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National Aeronautics
and Space Administration

December 20, 2002
NRA 02-OBPR-03

RESEARCH ANNOUNCEMENT

RESEARCH OPPORTUNITIES IN PHYSICAL SCIENCES

Cellular and Macromolecular Biotechnology
Combustion Science and Chemically Reacting Systems
Fluid Physics
Fundamental Physics
Materials Science

Proposals Due: March 28, 2003 THROUGH December 10, 2003

RESEARCH OPPORTUNITIES IN PHYSICAL SCIENCES

NASA Research Announcement
Soliciting Basic and Applied Research Proposals

NRA 02-OBPR-03
Issued: December 20, 2002

Office of Biological and Physical Research (OBPR)
National Aeronautics and Space Administration
Washington, DC 20546-0001

RESEARCH OPPORTUNITIES IN PHYSICAL SCIENCES

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RESEARCH OPPORTUNITIES IN PHYSICAL SCIENCES
SUMMARY AND SUPPLEMENTAL INFORMATION

NASA has a new Vision:

To improve life here
To extend life to there,
***To find life beyond*.**

The Office of Biological and Physical Research's (OBPR) contribution to the Agency to realize this Vision is written as a Mission Statement that motivates our research on the ISS and is the framework for the activities of OBPR:

Humans will extend the exploration of space. To prepare for and hasten the journey, OBPR must answer these questions through its research:

- **What new opportunities can scientific exploration bring to enrich lives and expand our understanding of the Universe?**
- **What technology must we create to enable the next explorers to go beyond where we have been?**
- **How can we assure survival of humans traveling far from Earth?**
- **What must we know about how space changes life forms, so that humankind will flourish?**
- **How can we educate and inspire the next generation to take the journey?**

OBPR is developing a Research Plan that will provide a top-level description of the direction that the Enterprise will take to answer these questions and fulfill its mission. The OBPR Research Plan will be available in January and can be accessed at the following Web site: http://spaceresearch.nasa.gov.

The Physical Sciences Research Division (PSRD) of OBPR is uniquely and strongly positioned to support OBPR's and NASA's mission through contributions to all aspects of the overarching organizing questions by virtue of research enabling integration of physical sciences and biological sciences. However, the Division's primary research emphasis will be focused on the two questions in the left column. The questions within the right column are the principal responsibility of the life sciences divisions within OBPR. All divisions contribute to the education and inspiration of the next generation. PSRD is developing more detailed plans that will be available in the mid-year timeframe. These detailed plans will be developed with and subject to modification by the national scientific community.

This NRA differs from previous announcements produced by the Physical Sciences Research Division in two principal areas: an increased emphasis on strategic research in support of NASA's long-term mission objectives, and an increased emphasis on connecting our research to education and public outreach activities.

This NRA has been written to reflect a closer alignment between the Physical Sciences Research program and NASA's long-term objectives in space exploration, as articulated by the NASA Exploration Team (NEXT). NEXT is chartered to create an integrated strategy for science-driven space exploration. Additional information on the NEXT initiative can be found on the Web at
http://HEDSAdvPrograms.nasa.gov/spaceexploration.html#NASAExplorationTeam

To this end, OBPR has categorized its research into three major research thrust areas: strategic, fundamental, and commercial. Although the Physical Sciences Research Division has historically focused on fundamental research, defined as basic and applied research to address the role of gravity in biological and physical processes, the strategic research thrust is not new to the PSRD research community. Previous NRAs have outlined and solicited research relevant to specific needs for human exploration technologies. Strategic research is defined here as basic and applied research that the Agency relies uniquely upon OBPR to conduct in order to enable NASA's mission to explore the Universe and search for life. PSRD is maintaining its commitment to fundamental research and is asking our research community to join us in the transition to strategic research.

The PSRD research contribution to the NASA mission is integrated across the disciplines within the Division. Each discipline encompasses specific expertise and research themes that are critical to the development of enabling technologies and performance enhancements for the NEXT mission strategies. In many instances, there is a seamless transition between the established fundamental research that has been the hallmark of PSRD and the more applied research supporting NASA's exploration goals. An excellent example is the basic research in microgravity materials processing addressing critical scientific questions of interest here on Earth, and providing the foundation for in-space fabrication technologies supporting exploration. Another example is the fundamental research in fluid physics in the areas of multi-phase flows and boiling in space that are essential to the development of future lower mass thermal control, power, and life support systems. Similarly, the combustion science community that is performing research to reduce pollution and enable more efficient usage of energy sources is also working to provide new technologies for improved fire safety to protect astronauts and facilities on-orbit and beyond. Conversely, strategic research focused on understanding how the low gravity space environment affects biotechnological processes (such as the development of tissue models and tissue engineering that enable the study of space-induced diseases including bone loss, muscle atrophy, and radiation damage) may ultimately help the many people who suffer tissue damage or organ failure from diseases or accidents by allowing medical treatments for these injuries without the complexity of finding tissue and organ donors. The clearest single component of fundamental research in the current program is in the discipline of fundamental physics. Researchers are working to expand the frontiers of physics by taking advantage of unprecedented opportunities to make definitive measurements in the laboratory of space to settle issues at the core of the fundamental understanding of nature. For example, instruments using super accurate atomic clocks are now being built for space-borne experiments that can probe Einstein's theory at an unrivaled level.

The specific objectives of the Physical Sciences Research program will, therefore, continue to be carried out by a multidisciplinary research community recruited from academia, industry, and other Government research agencies through this NASA Research Announcement. Top-level summaries of the various research elements, including information pertinent to this solicitation, such as research element goals, vision, and program scope, are provided in the following paragraphs. Therefore, anyone interested in applying to this NRA is urged to read the relevant parts of this section to decide whether their research interests are relevant to NASA OBPR/PSRD interests, and, if so, to which research element their proposal should be submitted. The appropriate Appendix should then be studied for a more complete understanding of the goals and direction of that program element. Table 1 lists these program elements in the order of their respective due dates for the submission of proposals. Questions about each element should be directed to the respective Enterprise Discipline Scientist, all of whom are identified in Table 1 and in the appropriate Appendix. <u>It is especially important to note that the overall objective of each of these program research elements is to contribute as effectively and directly as possible to OBPR/PSRD support of the NASA mission</u>. PSRD will attempt, as a first priority, to accommodate proposed experiments on existing hardware, and investigators are encouraged to propose against existing flight hardware. Further, all participants in this NRA are strongly encouraged to promote general scientific literacy and public understanding of physical sciences, the space environment, and the OBPR programs through formal and informal education opportunities. Where appropriate, supported investigators will be required to produce, in collaboration with NASA, a plan for communicating their work to the public (see Appendix F, Section VI).

Within the past year, the PSRD research portfolio has been reviewed by external expert committees, including one from the National Research Council, and suggestions have been made for research priorities. The elements of this research solicitation, summarized within the following paragraphs and described in detail in Appendices A–E, clearly reflect these recommendations.

Biotechnology Program

NASA's program includes both cellular and macromolecular biotechnology research for the International Space Station and other NASA missions. The goals are to advance the scientific understanding of biotechnology processes using low-gravity experiments, contribute to Earth-based biotechnology systems, and develop technologies to support NASA missions. NASA's cellular biotechnology program is developing new technologies for the growth of three-dimensional mammalian tissues and supports the development of reduced hydrodynamic-shear bioreactors that provide a model system for the low gravity conditions of space to the extent possible on Earth. The program seeks to 1) accelerate the development of advanced three-dimensional tissue culturing systems to support tissue engineering, 2) define and characterize mammalian cells and tissues that benefit from a low-shear environment, 3) use the microgravity environment of space as necessary to surmount the obstacles to the propagation of complex tissues, and 4) develop tissue models that support biomedical research in space and on Earth, including models for human disease studies and pharmaceutical testing. NASA's macromolecular biotechnology research encompasses 1) crystallographic analyses of complex and challenging systems, such as motor proteins, glycoproteins, and integral membrane proteins by using the space environment; 2) elucidation of the fundamental factors that provide for the observed benefits in diffraction performance when macromolecular crystals are grown in microgravity; and 3) research and development of leading-edge technologies for NASA missions in biomaterials and biological nanotechnology. Please see Appendix A for additional details.

Combustion Science and Chemically Reacting Systems Program

The Microgravity Combustion Science and Chemically Reacting Systems activity includes investigations of fundamental combustion processes, development of rational design procedures for maximizing efficiency and minimizing pollution associated with combustion processes on Earth, improvement of fire safety in reduced-gravity conditions, and development of combustion-related technologies that may aid in the human exploration of space. In this past year, the materials synthesis and processing area has been de-emphasized and new areas added in line with recommendations from external advisory groups and a decision by our upper management to increase emphasis on exploratory research. Areas of interest that have been added include micro-combustor technology; improved approaches to conversion of fuel to useful work or electricity in a microgravity environment; development of combustion approaches to converting waste to energy, plus a much-reduced residual volume; and technology permitting use of various chemical reactors (e.g., Reverse Water-Gas Shift reactors and Sabatier reactors) to allow production of building-block hydrocarbon materials using the largely CO_2 Martian atmosphere and water resources found on Mars or brought from Earth. Please see Appendix B for additional details.

Fluid Physics Program

The Fluid Physics Program engages a national research community in physics and engineering to meet NASA's needs by expanding the foundation of basic knowledge on the performance of fluid and thermal systems in space, and by developing the use of the space environment as a tool to advance science. Fluid physics research addresses critical questions that are vital to NASA's future planetary and human exploration missions (e.g., propulsion, power and life support), and enhances the nation's scientific and technical knowledge for applications on Earth (e.g., development of photonic devices via colloids research, and improvement in industrial and agricultural processes by studying granular materials). This reflects OBPR's emphasis of two broad research objectives: 1) research enabling human exploration of space (strategic research) and 2) research of high intrinsic scientific importance and impact (fundamental research). Some of the discoveries from our space experiments in the last few years include novel colloidal crystals and states, newly observed time-dependent regimes in surface-tension-controlled flows with consequences for materials processing applications, boiling with unpredicted heat transfer regimes, and new observations on the strength of granular materials at low confining pressures, far in excess of the predictions of current theory. Future priorities include development of a comprehensive scientific foundation for the design of high performance space heat transfer systems, as described in *Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies*, a report of the National Research Council (NRC) released in 2000, and basic research advancing the understanding and management of dusts and dust-laden flows, as described in the 2002 NRC report *Safe on Mars: Precursor Experiments Necessary to Support Human Operations on the Martian Surface.* Please see Appendix C for additional details.

Fundamental Physics Program

The Microgravity Fundamental Physics Program focuses on two primary objectives:

- To explore and understand the fundamental physical laws governing matter, space, and time; and
- To discover and understand the organizing principles of nature from which structure and complexity emerge.

By looking deeply into the smallest and largest pieces that make up the fabric of our universe, we hope to understand better the basic ideas that describe the world. While the basic laws of nature may be simple, the universe that has arisen under these laws is amazingly complex and diverse. By studying nature apart from Earth's gravity, we can understand better how the universe developed.

The PSRD Fundamental Physics element provides support for researchers striving to overcome the limitations imposed by gravity to test key elements of fundamental theories of nature and to develop novel approaches to experimental research enabled by the space environment. Initially, the program emphasized low-temperature and condensed matter physics, in particular critical phenomena and phase transitions, as these fields of research have been identified as the most likely to benefit from access to the low-gravity environment. Over the past decade, the program has shifted the focus of its longer-term research to laser cooling and atomic physics, and gravitational and relativistic physics. This NRA will continue this emphasis and will also focus on soliciting research-enabling advanced technology development in support to NASA's long-term scientific exploration of space. Please see Appendix D for additional details.

Materials Science Program

The five-year vision for OBPR involves a significant emphasis on strategic research, as noted in the introduction of this NRA. The Materials Science Discipline is essential to the PSRD transition to a more strategically focused research portfolio. The new emphasis on strategic materials science research is coordinated and aligned with current NEXT program initiatives and identified future needs. This emphasis is reflected in the solicitation described in Appendix E. The solicitation features two of OBPR's primary research thrusts: fundamental and strategic. The fundamental research thrust identified by the Materials Science Discipline Working Group (DWG), an advisory body to NASA's Physical Sciences Research Division, is classified in terms of fundamental physical and chemical phenomena, which the DWG believes would benefit from access to long-duration, high-quality microgravity conditions. Also included in the recommended fundamental research thrust are those activities that the DWG believes are required to fully realize the potential of microgravity research (e.g., process modeling, materials characterization, etc.). The recommended research areas are 1) thermodynamics and kinetics of phase transformation; 2) theory, modeling, and experimental control of microstructure and defect formation; and 3) nucleation process within and the properties of undercooled liquids. In addition to these areas of materials science, strategic research in areas that support NASA's exploration goals is a priority. Strategic materials science research, for the purposes of this solicitation, is comprised of two categories: in-space fabrication for exploration, and materials science for advanced space propulsion. Within the first category are the subtopics of fabrication of structural components, fabrication of solar sail systems, and modeling of environment and fabrication processes. Within the second category are subtopics focused on specific propulsion elements and systems: propellantless propulsion, electric propulsion, nuclear electric propulsion, advanced chemical propellants, and flight weight magnets. **It is expected that an AMENDMENT to this solicitation will be issued in the early summer timeframe of 2003 that will refine the focus within the broader areas outlined above.** Please see Appendix E for additional details on these research topics and subtopics**.**

Proposals for this NRA are due at 4:30 p.m. (Eastern time) on the due dates provided in Table 1 of this section. Proposals shall not be submitted electronically, with the exceptions being specified in this NRA. Proposals and Notices of Intent mailed through the U.S. Postal Service by express, first class, registered, or certified mail must be sent to the following address:

Name of Program Element
Physical Sciences Research Division NRA
NASA Peer Review Services
Suite 200
500 E Street SW
Washington, DC 20024
Telephone: 202-479-9030

Proposals and Notices of Intent that are hand-delivered or sent by commercial delivery or courier services are to be delivered to the above address between 8:00 a.m. and 4:30 p.m. (Eastern time). Proposals must be received by 4:30 p.m. on the proposal due date. The telephone number, 202-479-9030, may be used when required for reference by delivery services. NASA Peer Review Services (NPRS) cannot receive deliveries on Saturdays, Sundays, or federal holidays. NPRS will send notification to the investigator confirming proposal receipt within five business days of the proposal receipt date. There will not be a response directly from the Office of Biological and Physical Research.

The following items apply only to this Announcement:

Solicitation Announcement Identifier:	**NRA 02-OBPR-03**
Number of Copies Required:	**Original + 20 copies**
Notices of Intent Due:	**See Table 1**
Proposals Due:	**See Table 1**
Estimated Selection Announcement:	**See Table 1**
Selecting Official:	**Dr. Eugene Trinh, Director Physical Sciences Research Division Office of Biological and Physical Research**

Safety is NASA's highest priority. Safety is the freedom from those conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment. NASA's safety priority is to protect (1) the public, (2) astronauts and pilots, (3) the NASA workforce (including employees working under NASA instruments), and (4) high-value equipment and property. All research conducted under NASA auspices shall conform to this philosophy.

This NRA is organized such that

- Appendices A through E provide detailed descriptions of the research areas solicited by this Announcement.
- Appendix F contains specific instructions for this NRA, relevant application forms, and the evaluation criteria used in the selection process.
- Appendix G contains copies of the certifications required with any signed application.
- Appendix H provides reference instructions for responding to NASA Research Announcements.

Proposals submitted in response to this Announcement must address the research emphases defined in this Announcement. Those proposals that do not will be returned to the investigators. Other

Announcements calling for focused research or utilization of unique resources may be issued throughout the year. Unsolicited proposals received at other times during the year will be held until the next annual review period if the proposed research is relevant to the programs described in this Announcement. However, NASA reserves the right to act in the best interest of the federal government in the matter of proposal acceptance and evaluation.

Proposals are typically funded in one-year increments for activities lasting up to **four** years; however, the durations for the particular program elements are specified in Appendices A–E. The funding duration will depend on proposal requirements, review panel recommendations, and continuing progress of the activity. All proposals will be evaluated for overall scientific and technical merit by independent peer review panels. Relevance to NASA's programmatic needs and goals will be evaluated separately by NASA. Funds are not currently available for awards under the Physical Sciences Research Division NRA. The Government's obligation to make award(s) is contingent upon the availability of appropriated funds from which payment can be made and receipt of proposals that NASA determines are acceptable for award under this NRA. Typical funding amounts and anticipated numbers of award selections are also provided in Appendices A– E for the various program elements. Proposals for awards greater than these amounts must provide substantial justification. NASA does not provide separate funding for direct and indirect costs; thus, the amount of the award requested is the total of all costs submitted in the proposed budget. It is estimated that selections will be announced by the dates provided in Table 1 and grants, contracts without fee, or cooperative agreements awarded shortly thereafter.

Proposals selected for support through this NRA will generally be designated as either ground-based or flight definition investigations. (Other categories may be identified within specific program elements.) Investigators offered support in the ground-based program normally will be required to submit a new proposal for competitive renewal after no more than four years of support. Investigators offered flight definition status are expected to begin preparing detailed experiment requirements and concepts for flight experiment development shortly after selection in cooperation with the assigned representative from the appropriate NASA Center. Selected investigations will be required to comply with NASA policies, including the return of all appropriate information for inclusion in the NASA archives during the performance of and at the completion of the contract or grant.

Commitment by NASA to proceed from flight definition to the execution phase of a flight experiment will be made only after several additional engineering and scientific reviews and project milestones have established the feasibility and merit of the proposed experiment. Investigations that do not pass these reviews will be funded for a limited period (generally no more than four years from the initial award date) to allow an orderly closure of the project.

The Principal Investigator in flight definition must prepare a Science Requirements Document (SRD) early in the development of a flight experiment to guide the design, engineering, and integration effort for the instrument. The SRD describes specific experiment parameters, conditions, background, and justification for flight. Ground-based, normal, and reduced-gravity experimentation, as well as any necessary parallel modeling efforts, may also be required to prepare an adequate Science Requirements Document. The amount of support (technical, scientific, and budgetary) provided to investigators by NASA will be determined based upon specific investigator needs and the availability of resources to NASA and PSRD.

Participation in this program is open to all categories of U.S. and non-U.S. organizations, including educational institutions, industry, nonprofit institutions, NASA Centers, and other Government agencies. Historically Black Colleges and Universities (HBCUs), other minority educational institutions, and small businesses and organizations owned and controlled by socially and economically disadvantaged individuals or women are particularly encouraged to apply. Guidelines for International Participation are detailed in paragraph I of Appendix H of this announcement.

A Notice of Intent (NOI) to propose is requested by the dates provided in Table 1 of this summary. Instructions for preparation of a Notice of Intent are provided in Appendix F of this Announcement. A Notice of Intent is not a prerequisite to submit a proposal; however, all who intend to propose are strongly encouraged to submit an NOI. Notices of Intent should be submitted via the World Wide Web (WWW) at

http://proposals.hq.nasa.gov/proposal.cfm

If you do not have access to the WWW, you may submit a notice of intent via email to

noi@hq.nasa.gov

The subject heading of the email message should read “Notice of Intent: SUBJECT: 02-OBPR-03.” If you do not have access to email, you may submit a notice of intent by U.S. Postal Service or commercial delivery to the address listed for proposal submission.

In order to be accepted as a complete submission, proposals must include all information requested in Appendix F. Additional technical information is available from

Dr. Bradley Carpenter
Physical Sciences Division
Code UG
NASA Headquarters
Washington, DC 20546-0001
Telephone: 202-358-0826
Fax: 202-358-3091
Email: bcarpent@hq.nasa.gov

The specific contracting point of contact will be specified in each selection notification letter.

This Announcement is restricted to the program named above and described in detail in Appendices A–E. Potential investigators should read with care the program descriptions that are of interest and focus their proposals on the specific research emphases defined in this Announcement.

Because this Physical Sciences NRA is being released far in advance of many of the deadlines given in Table 1, additional programmatic information for any given entry may develop before proposals are due. If so, such material will be added as an <u>Amendment</u> to this NRA and posted at the NRA Web site no later than 90 days before the proposal deadline. Proposal due date extensions may be made less than 90 days prior to the date shown in Table 1 for specific program elements. Although NASA OBPR/PSRD will also send an electronic alert of any such amendments to all subscribers of its electronic notification system (see below), <u>it is the responsibility of prospective investigators to check this NRA Web site for updates concerning the program element(s) of interest</u>.

OBPR/PSRD requires the electronic submission of certain key elements of proposals through the World Wide Web (as referenced previously and described in detail in Appendix F), and this practice continues with this NRA. While effort is made to ensure the reliability and ease of accessibility of this Web site, and to maintain a point of contact for assistance via email, difficulty in accessing and/or using this site may arise at any point on the Internet including the user’s own equipment. Therefore, <u>prospective investigators are urged to familiarize themselves with this site well in advance of the deadline(s) of the program element(s) of interest</u>.

OBPR maintains an electronic notification system to alert interested subscribers of the impending release of its research program announcements and amendments. To subscribe to this service, access the OBPR Research Opportunities Web site at http://research.hq.nasa.gov/code_u/code_u.cfm; click on “*Add yourself to the OBPR mailing list.”* This requires registration (including specification of your fields of interest) in the SYS-EYFUS database (described in detail in Appendix F). Regardless of subscription to this service, all OBPR Research Announcements may be accessed on the Web as soon as they are posted (about 8:30 a.m. Eastern on the day of release) through *Research Opportunities* on the OBPR homepage.

Your interest and cooperation in participating in this effort is appreciated.

Original signed by

Mary E. Kicza
Associate Administrator
Office of Biological and Physical Research

TABLE 1

SCIENCE PROGRAM ELEMENTS SOLICITED IN NRA 02-OBPR-03
(in order of proposal due dates)

NRA Appendix	Science Program Element	Proposal Open Period Starts	NOI Submission Due Date	Proposal Due Date	Estimated Selection Announcement	Point of Contact Information
B	Combustion Science and Chemically Reacting Systems	12/20/02	01/31/03	03/28/03	September 2003	Dr. Merrill King Telephone: 202-358-0817 Email: merrill.king@hq.nasa.gov
D	Fundamental Physics	01/24/03	02/25/03	04/25/03	October 2003	Dr. Mark C. Lee Telephone: 202-358-0816 Email: mark.lee@hq.nasa.gov
A	Biotechnology	04/30/03	05/30/03	07/31/03	January 2004	Dr. Stephen C. Davison Telephone: 202-358-0647 Email: sdavison@hq.nasa.gov
E	Materials Science	06/30/03	07/30/03	09/30/03	March 2004	Dr. Michael J. Wargo Telephone: 202-358-0822 Email: mwargo@hq.nasa.gov
C	Fluid Physics	09/10/03	10/10/03	12/10/03	June 2004	Dr. Francis Chiaramonte Telephone: 202-358- 0693 Email: fchiaram@hq.nasa.gov

APPENDIX A
NRA 02-OBPR-03

CELLULAR AND MACROMOLECULAR BIOTECHNOLOGY: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

I. INTRODUCTION

NASA's Biotechnology Program currently includes both cellular and macromolecular biotechnology, including research on tissue engineering and challenging structural biology problems, respectively. This NRA solicits research to establish the scientific foundations for future experiments on the International Space Station and to support the development of biotechnology applications to NASA missions. The program seeks a coordinated research effort involving both space- and ground-based research through the solicitation of experimental studies that require the space environment and ground-based studies that will lead to the definition of potential flight experiments or to the development of new technologies for future NASA missions.

<u>The scope of this research announcement does not include research dealing with the response of living organisms to weightlessness, an area that is the focus of ongoing programs in the Fundamental Space Biology and Bioastronautics Research Divisions</u>.

NASA has as a major goal contributing significantly to the opening of the space frontier and expanding the human experience. The focus of the Office of Biological and Physical Research is to foster fundamental understanding of physical, chemical, and biological processes, building a foundation of knowledge that can be applied to Earth- and space-based technologies. Specifically, understanding of the fundamental role of gravity in the space environment in these processes is needed to achieve breakthroughs in science, and to develop enabling technology for exploration of space. The need for improved understanding of biotechnology phenomena and development of new technologies to enable future space technologies and operations should be recognized as opportunities of the discipline.

While basic research is still of major importance to our program, there is a shift of emphasis toward strategic (mission-oriented) research, that is, research aimed at specific problems in biotechnology to enable space exploration as well as for Earth-based applications. Thus, it is important that firmer links be developed between the research in support of the exploration of space and practical applications on Earth. These strategic interdisciplinary proposals are not limited to the topic areas discussed in this Appendix; extension to biotechnology topics not currently included in NASA's Biotechnology Program is strongly encouraged to allow us to broaden the program scope.

II. PROGRAM RATIONALE

Biotechnology research and development promotes economic competitiveness.

Biotechnology has as its central mission the development of novel biological solutions for the public health, agriculture, and many other important economic areas. Advances in biotechnology will benefit a wide range of applications and research areas. For example, the emerging area of tissue engineering may help the many Americans who suffer tissue damage or organ failure from diseases and accidents every year. With the yearly cost of treating these patients in the billions of dollars, tissue engineering research may allow medical treatments for many of these injures without the complexity of finding tissue and organ donors. In the pharmaceutical industry, structural biology leads to both fundamental understanding of life processes and the design of new treatments for disease. Many new drugs and improvements to existing drugs would never reach the patient if not for the molecular analysis of the proteins they target.

With the understanding of how the low gravity environment of space affects biotechnological processes, researchers should develop new science and technology to ensure national leadership in space experiments and Earth applications.

Use of the microgravity environment is just beginning to increase our understanding of the biological sciences and to enable us to develop innovative biotechnological processes that can exploit space. Expansion of biological technologies requires an understanding of the fundamental processes on which these technologies are based. NASA is currently defining an interdisciplinary program that will study those processes that are affected by buoyancy-driven convection and sedimentation and that can be gainfully studied using the low-gravity (diffusion controlled transport) environment of space. Gravity's effect on these processes can be virtually eliminated in space, thus allowing space-based experiments, coupled with ground-based experimental and theoretical research, to provide insights into biotechnological processes. NASA's goals are to exploit the unique environment of space to advance the scientific understanding of biotechnology processes, use the scientific knowledge gained through space experimentation on a wide range of biotechnology applications, contribute to Earth-based systems concerned with biotechnology, and develop technologies specifically supporting NASA activities.

Biotechnology research must contribute significantly to human space exploration by providing technological advances for biomedical research, life support, and biological research.

A major goal of NASA is to open the space frontier and expand the human experience. To reach this goal, new technologies are required for studying and maintaining astronaut health and associated life support systems. Biotechnology can contribute significantly to human space exploration by providing technological advances for biomedical research, life support, and biological research. For example, development of tissue models that enable the study of space-induced diseases including bone loss, muscle atrophy, and radiation damage can help minimize the use of animals in space research. Biotechnology can also be used to reduce NASA mission requirements such as weight, volume, electrical power, etc. To realize these benefits, the fundamental role of gravity in biotechnological processes needs to be studied to achieve breakthroughs in scientific understanding, and to develop enabling technology for exploration of space.

III. RESEARCH AREAS OF INTEREST

TISSUE ENGINEERING

NASA has developed low-shear bioreactor technology and uses the low gravity environment of space to provide a unique three-dimensional cell culture setting that addresses applied and fundamental cell science challenges associated with tissue engineering. Ground-based research studies demonstrate that both normal and neoplastic cells and tissues recreate many of the characteristics in the NASA bioreactor that they display *in vivo*. Generations of the appropriate cytoarchitecture and inherent tissue function have occurred in the engineering of cartilage, cardiac muscle, kidney, and other tissues using the NASA bioreactor technology. In addition, the space environment affords a unique opportunity to culture cells because they may be grown in an extremely low-shear environment without sedimentation. This provides the setting to readily assemble cells and recreate the three-dimensional relationships among cells that are extremely important to normal tissue morphogenesis and, thereafter, organ function. Results reported on long-duration tissue engineering experiments on Mir validated tissue morphogenesis in space and demonstrated unique characteristics of tissue produced in the microgravity environment of space. The cell science component of this program is directed at understanding the role of reduced hydrodynamic stress and microgravity on mammalian cell adhesion, proliferation, and eventual differentiation. Research proposals that address the following areas are sought in this subtopic:

- Development of tissue models that support biomedical research in space and on Earth including models for bone loss, muscle atrophy, and radiation risks
- Engineered tissue platforms for drug testing and biopharmaceutical production

- Research to assess the value of low-shear culturing and tissue engineering using rotating wall vessels
- Use of the microgravity environment of space to surmount obstacles to the propagation of complex tissues
- Development of functional and differentiated tissues for use in transplantation

BIOREACTOR DESIGN AND TECHNOLOGIES FOR TISSUE ENGINEERING

A recent NRC report (see bibliography) recommended that NASA support the development of new technologies, such as miniaturized culture systems and compact analytical devices that enhance ISS biotechnology experiments in cell science and tissue engineering. Therefore, research to address these NRC recommendations is solicited in this NRA.

The physical environment in which cells and tissue are cultured has a dramatic effect on the differentiation of the cells and the resulting tissue cytoarchitecture. NASA is coupling fluid physics, biomaterials, and automated control systems into its tissue engineering program with the goal of generating novel bioreactor designs with enhanced transport and appropriate fluid shear properties to support the growth of complex tissue constructs. Research proposals that address the following areas are sought in this subtopic:

- Miniaturized culture systems for ISS cell science and tissue engineering research
- Compact analytical devices that support ISS research activities in cell science and tissue engineering
- Research into new tissue culture technologies and approaches that support three-dimensional tissue propagation (for example, perfusion or pulsed-flow methods)
- Research on fluid modeling and the effect of reduced levels of hydrodynamic shear and the role of mass transport on cellular propagation and tissue assembly in rotating wall bioreactor systems
- Research to support the development of technologies (biosensors for pH, glucose, and oxygen levels, etc.) and maintenance strategies for three-dimensional tissue culture to allow long-term automation and improve the tissue culturing process via a more physiologically balanced system
- Biomaterials and scaffolds for tissue engineering: biopolymer and biomaterials research that supports growth of anchorage-dependent cells and allows tissue to form with the correct morphology

CHANGES IN CELLULAR FUNCTION

Gene array analysis of cultured human renal cells was used to do the first comprehensive analysis of the microgravity-induced adaptive responses as demonstrated in the expression of 10,000 genes. Renal cells were grown in microgravity, on the ground using the rotating wall vessel culture system, and in a centrifuge at 3g. While only 5 genes changed more than 300 percent during 3g centrifugation, 1,632 genes changed in microgravity, and 914 genes changed in the rotating wall vessel. Thus, renal cells display discrete responses to changes in their gravitational environment during growth. Research in this area will demonstrate the use of space as a potential probe to discover new cellular regulatory systems and reactions. Such discoveries can open new strategies in understanding disease processes and advance our knowledge of cellular processes necessary for invoking low gravity research and technologies to support basic and applied science goals. Research proposals that address the following areas are sought in this subtopic:

- Studies on gene expression
- Research into metabolic adaptations
- Cytoarchitecture studies including membrane composition and cytoskeletal array

CHALLENGING STRUCTURAL BIOLOGY PROBLEMS

A recent NRC report (see bibliography) has recommended that NASA fund a series of grants to support research that uses microgravity to produce crystals of macromolecular assemblies with important implications for cutting-edge biology problems. The NRC report stated that the success or failure of these research efforts would definitively resolve the issue of whether the microgravity environment can be a valuable tool for structural biology.

Therefore, requests for structural biology research proposals that address the NRC report recommendations are solicited in this NRA. Some examples of classes of systems that currently meet these criteria include the following: membrane proteins, molecular motors, and biopolymer synthetic machinery (e.g., origin of replication complexes and transcriptional pre-initiation complexes). The NRC report described all of these systems as elaborate and fragile, which makes them difficult to crystallize unless the conditions are just right; microgravity might improve the quality of the crystals enough to increase the resolution to a level at which key structures can be discerned. For example, macromolecular assemblies that have been resolved to approximately 4 angstroms could benefit if microgravity crystallization allowed improvement to 3.5 Angstroms, where alpha helices and beta sheets could be more accurately discerned.

Challenging problems in structural biology where efforts are already underway, although crystallization has been difficult, would be favored over nascent research projects in this area.

Research areas included under this subtopic are as follows:

- Extending crystallographic analyses to more complex and challenging systems such as molecular motors, glycoproteins, and integral membrane proteins by using the space environment
- Elucidation of the fundamental factors that provide for the observed benefits in diffraction performance when macromolecular crystals are grown in microgravity
- Use of the microgravity environment of space to support neutron diffraction studies by growing larger, high-quality crystals on the order of millimeters

BIOLOGICAL NANOTECHNOLOGY AND BIOMATERIALS

NASA is looking to expand its current activities in protein-based materials for application to future NASA missions. Biological nanotechnology and biomaterials can be used to reduce NASA mission requirements such as weight, volume, electrical power, etc. Biological molecules can be incorporated into nanotechnology development in several ways: biological molecules or assemblies could serve as molecular-sized sensors, genetic engineering could be used to produce a single molecule with both a molecular receptor and a signal function, etc. Research on structural proteins such as collagen, keratin, and silk may form the basis for producing a variety of hierarchical structures that are characterized by the ability to undergo biomolecular self-assembling. Structural protein-based materials may be able to incorporate novel properties by genetically engineering the sequences or incorporating modular components from other proteins. Finally, these systems may be able to be produced very reliably and economically because biological systems are capable of manufacturing large molecules in a highly reproducible manner, far more reproducible than any corresponding industrial processes.

Proposals in this area must distinguish themselves from research sponsored by other Federal agencies; the unique application to NASA missions or need for NASA sponsorship must be made clear. Research proposals that address the following areas are sought in this subtopic:

- Development of engineered biological systems that can be exploited for applications such as ultrafiltration membranes or solid enzyme catalysts
- Research on the fabrication of complex, self-assembling protein devices and materials for NASA applications

- Research on structural protein-based materials that incorporates novel properties for use in NASA activities

SEPARATION, PURIFICATION, AND REMEDIATION METHODS

Separation and purification methods to clean and recycle water are technologies needed to reduce the costs of exploration in long-duration space flight research. For example, cell and tissue systems require significant amounts of pure water for long-duration space studies. Purification methods must be specific for toxic molecules, reliable, inexpensive, and make small demands on spacecraft resources such as power, mass, and volume. Remediation of fluids is an important enabling technology for space flight. One possible biological application is the use of cellular organisms or biological molecules to convert or catalyze fluid waste to usable products, such as potable water, oxygen, methane, etc.

Related research in life support is also being solicited through the Advanced Human Support Technology (AHST) Program of the Bioastronautics Division. Collaborative research is encouraged in development of life support systems essential to the viability of future long-duration human space flight and includes air revitalization, water recycling, solid waste processing and subsequent resource recovery, and food processing and biomass production.

More details on current research and future AHST solicitations can be found at the following Web site: http://research.hq.nasa.gov

SELECTIVE PRESSURES ON CELL POPULATIONS

Critical for humanity's long-term occupation of space is the assessment of selective pressures on mammalian and microbial cell populations. The induced phenotypic and genotypic changes need to be assessed through generations of cell populations sustained in the space environment (low gravity, etc.). The development of unique technologies and methodologies to enhance research on selective pressures will apprise us of the risks to our biological integrity and to our life-based support systems.

DEVELOPMENT OF BIOSENTINEL TECHNOLOGIES

Genome damage from ionizing radiation is a primary source of DNA mutation. NASA is seeking new technologies to monitor mutation levels in DNA. Biosensor and biosentinel systems to monitor radiation effects and other space environmental factors (magnetic fields, atmospheres, gravitational fields, etc.) on cell replication and DNA for manned and unmanned robotic science missions are needed. These biosentinel systems for exploratory research may incorporate biomolecules in their detection systems. DNA biosentinel technology will be important for future exploration of space by humans.

MICROBIOSENSOR MONITORING DEVICES

Micro- and Nano-technology based sensors for use in biological systems and experiments may have unique application to long-duration space missions. The development of extremely stable and small biosensor devices is central to the advancement of many biotechnological processes and their use in support of long-duration space missions.

APPLICATION OF EXTREMOPHILIC ENZYMES

Certain bacteria and archeabacteria have been found to flourish in extreme environments: high and low temperatures, high and low pH, etc. The unique and robust enzymes produced by these organisms, or the organisms themselves, can have applications in industry and may be of substantial benefit for certain chemical processes involved in long-duration space flight or colonization of the Moon and Mars. The specificity of enzymes is superior to conventional catalysts and can serve to eliminate multi-step reactions and unwanted side products, making the overall chemical process much more efficient. Research in this area must identify and establish unique application of extremophiles or their enzymes in support of exploration goals.

IN SITU RESOURCE UTILIZATION EMPLOYING BIOLOGICAL TECHNOLOGIES

The phrase *in situ resource utilization* has been used to describe the utilization of ores or soils of foreign planets, moons, or asteroids for the production of materials needed for space exploration. Identification or engineering of cells or molecules with the potential to catalyze the production of materials such as oxygen, hydrogen, methane, etc. using alien materials is of interest. Biologically based catalysts are of particular interest since they can be efficient and effective at moderate and low temperatures that are often impractical for standard industrial processes. Biological molecules can be genetically engineered and expressed for the purposes of isolating particular compounds or metals from soil.

GENETIC ENGINEERING OF BIOMOLECULES FOR LONG-TERM SPACE FLIGHT

Cells and subcomponents of cells are efficient chemical plants, reproducibly manufacturing numerous, large, and multifunctional compounds. Genetic engineering allows the manipulation of cells to produce these compounds of specific interest. In most cases, this production is difficult or impossible by standard organic chemistry. Cells such as *Escherichia coli*, yeast, etc. can be engineered to produce one or more compounds. Possible uses for genetically engineered proteins would be nutrients and medicines of value for spacefarers, or a protein-based artificial blood for emergency situations. Ideally, genetically engineered cells would be stored in an inactive state. When needed, the cells could be cultured and the required material expressed.

IV. HARDWARE AND FACILITY DESCRIPTIONS

NASA is pursuing a program for the development of payloads capable of accommodating multiple users and their science requirements. <u>In the interest of minimizing project cost and complexity, NASA encourages the use of existing U.S.- or internationally-developed space hardware whenever consistent with experiment requirements.</u>

A list of the flight hardware available or planned for use in the Cellular and Macromolecular Biotechnology Program is given below. Detailed descriptions of this hardware can be obtained at the following Web site:

http://spaceresearch.nasa.gov/research_projects/nrahardware.html

International equipment described here may be offered for flight on a cooperative basis with agencies from various countries. The availability of the hardware described in this section is contingent upon the availability of funds, flight manifest opportunities, and, for international hardware, cooperative agreements between NASA and the appropriate foreign space agency.

A. ISS MICROGRAVITY SCIENCE GLOVEBOX (MSG)

B. MACROMOLECULAR BIOTECHNOLOGY

1. Thermal Enclosures: Single Locker Thermal Enclosure System (STES)
   Thermal Enclosure System (TES)

   Use of the Single-locker Thermal Enclosure System (STES) or the Thermal Enclosure System (TES) is encouraged for investigations requiring experiment temperature control.

2. Protein Crystallization Apparatus for Microgravity (PCAM)

3. Diffusion-controlled Protein Crystallization Apparatus for Microgravity (DCAM)

4. Protein Crystallization Facility - Light Scattering Temperature (PCF-LST)

5. Protein Crystallization Facility - Variable Gradient (PCF-VG)

6. Protein Crystallization Diagnostics Facility (PCDF) (European Space Agency/ESA)

7. Interferometer for Protein Crystal Growth (IPCG)

8. Dynamically Controlled - Protein Crystal Growth (DC-PCG)

9. Observable Protein Crystal Growth Apparatus (OPCGA)

C. CELLULAR BIOTECHNOLOGY

The Cellular Biotechnology flight research hardware provides the technological capability for conducting cell science and tissue engineering research in microgravity.

1. Biotechnology Facility (BTF) - available Sept. 2006

2. Rotating and Perfused Bioreactor Systems
   Engineering Development Unit (EDU)
   Rotating Wall Perfusion System (RWPS)
   Automated Rotating Culture System (ARCS), under development
   Cell Culture Unit (CCU), under development

3. Static Cell Culture Systems
   Biotech Specimen Temperature Controller (BSTC)

4. Support Equipment
   ARCTIC
   BCSS
   Biotech Refrigerator (BTR)
   Cell Bio Cryodewar (CBC)
   Experiment Control Computer (ECC)
   Gas Supply Module (GSM)

5. Ground-Based Research Equipment
   Slow Turning Lateral Vessel STLV
   High Aspect Rotating Vessel HARV
   Hydrodynamic Focusing Bioreactor HF

D. OTHER BIOTECHNOLOGY FLIGHT HARDWARE

1. Light Microscopy Module (LMM)

2. Commercial Generic Bioprocessing Apparatus (CGBA)
   Fluid Processing Apparatus (FPA)
   Group Activation Pack (GAP)
   GBA-INC
   GBA-ICM

3. ADvanced SEParations (ADSEP)

4. Materials Dispersion Apparatus (MDA) Minilab

V. NRA FUNDING AND SCHEDULE

The total amount of funding for this program is subject to the annual NASA budget cycle. Funds are not currently available for awards under the Cellular and Macromolecular Biotechnology area of the Physical Sciences Research Division NRA. The Government's obligation to make award(s) is contingent upon the availability of appropriated funds from which payment can be made and receipt of proposals that NASA determines are acceptable for award under this NRA. For the purposes of budget planning in the Cellular and Macromolecular Biotechnology Program, we have assumed that three (3) highly meritorious flight experiment definition proposals will be funded. These efforts are typically funded at an average of $200,000 per year. It is also anticipated that approximately 10 ground-based investigations from those judged to be highly meritorious will be funded, at an average of approximately $170,000 per year for up to 4 years.

The initial fiscal year funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts.

All proposals submitted in response to this Announcement are due on the date and at the address given below by the close of business (4:30 p.m. EDT). NASA reserves the right to consider proposals received after this deadline if such action is judged to be in the best interest of the U.S. Government. A complete schedule of the review of the proposals is given below.

Notice of Intent Due:	**May 30, 2003**
Proposal Due:	**July 31, 2003**
Final Selections:	**January 2004**
Funding Commences:	**No sooner than April 2004**

VI. BIBLIOGRAPHY

The *Office of Biological and Physical Research Tasks and Bibliography*, which contains a searchable database on currently funded research, may provide useful information to investigators and can be viewed at the following Web site: http://research.hq.nasa.gov/taskbook.cfm

NRC Report on *Future Biotechnology Research on the International Space Station* is available at the following Web site: www.nationalacademies.org/ssb/btfmenu.htm

Questions about this program element may be directed to the Microgravity Biotechnology Enterprise Scientist:

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APPENDIX B
NRA 02-OBPR-03

MICROGRAVITY COMBUSTION SCIENCE AND CHEMICALLY REACTING SYSTEMS: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

I. INTRODUCTION

NASA's support for research in Microgravity Combustion Science has steadily grown over the past two decades. This research program supports theoretical and experimental investigations in ground-based facilities, taking advantage of the limited low gravity test times available in the drop-towers at the NASA Glenn Research Center. These ground-based experiments, along with theoretical modeling, sometimes mature to the point that they become the focus of well-defined flight experiments, utilizing sounding rockets, space shuttle flights, and International Space Station (ISS) facilities.

The need for improved understanding of combustion phenomena to enable future space technologies and operations should be recognized as one of the primary opportunities of the discipline. Included are development of spacecraft combustion/propulsion systems, fire safety, use of in-situ resources for production of fuels and/or plastics, and power generation in extraterrestrial environments. In the area of spacecraft fire safety, better characterization of flammability of various materials, improved fire detection, and improved fire suppression under microgravity conditions are of importance. At a Spacecraft Fire Safety Workshop held in June 2001, a number of experts in various disciplines related to spacecraft fire safety were brought together to (1) identify research needed to ensure fire safety in future shuttle and International Space Station (ISS) systems and payloads; (2) promote ISS fire safety through proposals for innovative designs, operations, and validation procedures; (3) identify areas of concern related to fire safety inherent to long-duration space missions in Earth orbit and beyond; and (4) anticipate research required to plan and design habitats for planetary exploration. Further details on this workshop may be found on the Web at http://www.ncmr.org/events/firesafety.

While basic research is still considered to be of major importance to our program, recently there has been a major shift of emphasis toward strategic research, that is, research aimed at specific problems in combustion applications under reduced or microgravity conditions in extraterrestrial missions. We are therefore turning to an increased emphasis on research aimed at aiding space exploration, beyond the fire safety studies referred to above. Areas of interest that have been added include micro-combustor technology, improved approaches to conversion of fuel to useful work or electricity in a microgravity environment, development of combustion approaches to converting waste to energy along with a much-reduced residual volume, and technology permitting use of various chemical reactors (e.g., Reverse Water-Gas Shift reactors and Sabatier reactors) to permit in-situ production of building-block hydrocarbon materials using the largely CO_2 Martian atmosphere and water resources found on Mars or brought from Earth.

In addition, we continue our support of fundamental research to benefit people on Earth. It is important that firmer linkages between the research being done using microgravity and applications to practical applications on Earth (e.g., increased efficiency of conversion of chemical energy contained in fuels to useful work, reduction of combustion-generated pollutants from automobile engines and other combustors, decreased fire and explosion hazards) be established for an increasing percentage of efforts funded under this program.

II. PROGRAM RATIONALE

Combustion processes play a major role in the Nation's economy, but in so doing result in production of undesired byproducts (pollutants).

Combustion has been a subject of increasingly vigorous scientific research for over a century, which is not surprising considering that combustion accounts for approximately 85 percent of the world's energy production and is a key element of many critical technologies used by contemporary society. For example, electric power production, home heating, surface and air transportation, space propulsion, and materials synthesis all utilize combustion as a source of energy. Although combustion technology is vital to our standard of living, it poses great challenges to maintaining a habitable environment. Pollutants, atmospheric change and global warming, unwanted fires and explosions, and the incineration of hazardous wastes are major problem areas that would benefit from improved understanding of combustion. Thus, combustion phenomena have unusually large impacts on major problems facing us today. The United States alone consumes approximately 90 quadrillion BTU of energy per year, at a cost of approximately $400 billion (assuming $25 per barrel of oil). Of this amount, approximately 90 percent uses combustion processes to generate the desired products of heat or work.

Study of the details of combustion processes is greatly complicated at normal gravity by buoyancy effects; the use of microgravity eliminates buoyancy and its associated complications.

Effects of gravitational forces on Earth impede combustion studies more than they impede most other areas of science. Combustion intrinsically involves the appearance of high-temperature gases whose low density triggers buoyant motion under normal gravity conditions, vastly complicating the execution and interpretation of experiments. The effects of buoyancy (proportional to gravity level) are so ubiquitous that we often do not appreciate the enormous negative impact that they have had on the rational development of combustion science. Perversely, the effects of buoyancy are strongest in the highest temperature regions of flames, where most of the chemical reactions occur. This causes these reaction zones, where current understanding is most limited, to collapse into very thin sheet-like regions not resolvable by existing or anticipated instrumentation. Buoyant motion also triggers the onset of turbulence, yielding unsteady effects as an additional complication. Finally, buoyancy causes particles and drops to settle, inhibiting studies of heterogeneous flames important to furnace, incineration, and power generation technologies. Microgravity offers potential for major gains in combustion science understanding in that it offers a unique capability to establish the flow environment rather than having it dominated by uncontrollable (under normal gravity) buoyancy effects, and through this control extend the range of test conditions that can be studied.

With the understanding of fundamental combustion subprocesses that can be obtained from microgravity testing, rational approaches to improved combustor design can be developed.

A major goal of microgravity combustion research is production of fundamental (foundational) knowledge that can be used in developing accurate simulations of complex combustion processes, replacing current "cut-and-try" approaches and allowing developers to improve the efficiency of combustion devices, to reduce the production of harmful emissions, and to reduce the incidence of accidental uncontrolled combustion (fires, explosions). It appears that the most fruitful approach to achieving meaningful technology gains in processes involving combustion is to concentrate on developing better understanding of the fundamentals of the individual processes involved (e.g., transport mechanisms, chemical kinetics, stability). With full understanding of the physics and chemistry involved in a given combustion process, including details of unit processes and their interactions, physically accurate models for use in parametric exploration of new combustion domains via computer simulation can be developed, with possible resultant definition of radically different approaches to accomplishment of various combustion goals.

Differences in combustion processes under microgravity conditions must be addressed and quantified in order to maximize fire safety on orbiting vehicles such as the International Space Station.

Fire and/or explosion events aboard spacecraft could be devastating to international efforts to expand the human presence in space. Accordingly, NASA seeks to improve fire safety aboard spacecraft such as the Shuttle and the International Space Station. Testing to date has shown that ignition and flame spread on fuel surfaces (e.g., paper, wire insulation) behave quite differently under partial gravity and microgravity conditions. In addition, fire signatures—i.e., heat release, smoke production, flame visibility, and radiation—are now known to be quite different in reduced gravity environments; this research has provided data to improve the effectiveness of fire prevention practices, smoke and fire detectors, and fire extinguishment systems. The more we can apply our scientific and technological understanding to potential fire behavior in microgravity and partial gravity, the more assurance can be given to those people whose lives depend on the environment aboard spacecraft or eventually on habitats on the Moon or Mars.

The value of microgravity combustion research is shown by definition of desirable results, identification of key barriers to achieving them, and demonstration of how microgravity research overcomes these barriers.

One approach to defining the value of the microgravity combustion program is through definition of desirable benefits, identification of key scientific barriers to achievement of such benefits, and discussion of how microgravity studies can be utilized to overcome these barriers. One goal of combustion research is reduction of combustion-generated pollutants that pollute the atmosphere and lead to global warming. Barriers to progress in this area include lack of understanding of reaction, pyrolysis, and devolatilization kinetics; of soot nucleation, growth, and oxidation processes; of flame stabilization mechanisms; and of kinetic-transport interactions. Microgravity research can contribute to overcoming these barriers by providing increased spatial resolution through use of larger length scales that cannot be achieved at normal gravity without confounding buoyancy effects. Another potential benefit of combustion research is reduction of fire and explosion hazards. Technological barriers here include lack of understanding of flammability limit mechanisms, ignition limit mechanisms, smolder-to-fire transition, and fire growth processes; microgravity studies can contribute significantly here by elimination of the intrusion of buoyancy effects which obscure these fundamental phenomena under normal gravity conditions. A third goal is development of improved hazardous waste incineration processes, currently hindered by lack of understanding of reaction pathways leading to pollutants and toxic products; microgravity can help by providing improved spatial resolution, long controllable residence times, and elimination of settling of condensed phase species. Still another objective is development of increased efficiency of conversion of chemical energy stored in fuels to useful heat and work; progress is hampered at normal gravity by lack of understanding of soot production processes, turbulence-flame interactions, droplet vaporization, near-critical behavior, and very fuel-lean combustion. Microgravity is useful here in providing controllable residence times, reducing turbulence scales to allow direct model comparison, providing truly one-dimensional geometries (allowing meaningful comparison of tractable models with data), and general simplification of experiments.

III. RESEARCH AREAS OF INTEREST

At this time, we are funding approximately 20 flight and flight definition and 30 ground-based investigations (with an additional incoming 22 ground-based investigations already selected from NRA 01-OBPR-08, whose initiation has been delayed to October 2003 due to funding constraints). These may be broken out into a number of categories and subcategories as follows, the first two categories emphasizing mainly fundamental research while the latter two categories place more emphasis on strategic research. In the future, additional concentration on strategic research topics is planned.

Gaseous Flames: Diffusion Flames, Premixed Flames, Partially Premixed Flames, Triple Flames, Flame-Vortex Interactions, Kinetics, Electrical Field Effects, Magnetic Field Effects, Flame Suppression, Edge Flames

Droplets, Sprays, Particles, and Dust Clouds: Single Droplets, Droplet Arrays, Sooting Droplets, Sprays, Particle Combustion, Dust Clouds, Bubble Combustion

Surface Combustion/Fire Safety: Flame Spread, Flammability Testing, Flame Detection, Extinguishment, Smoldering, Liquid Pool Combustion, Secondary Fires

Miscellaneous: Cold Boundary Flames, Diagnostics Development, Nanotubes

[Note that the Combustion Synthesis area, previously included in the program, has been deleted based on prioritization recommendations by the Research Maximization and Prioritization (REMAP) task force, an ad-hoc external advisory committee established in early 2002. Single-walled Nanotube and Nanofiber production, however, is still included as an area of interest since it is considered to fall in the category of phase transformation rather than combustion synthesis.]

More information regarding these programs can be obtained from papers in the Proceedings the Sixth International Microgravity Combustion Workshop (May 2001), available at http://www.ncmr.org/events/combustion2001/index.html.

Future Thrusts

In line with plans being developed to place more emphasis on relating our research to enhanced space exploration activities, we plan to rapidly expand this program into additional strategic research activities in the years to come, covering a much wider range of reacting flow phenomena. Examples of activities of interest to this new program emphasis include:

Additional innovative approaches to fire detection and suppression: Although we are already placing considerable emphasis on fire safety on extraterrestrial vehicles (notably the Space Shuttle and the International Space Station), numerous additional technology developments are needed, particularly in the detection of deep-seated fires and in effective methods of extinguishments of fires with minimal residual damage to vehicle crew and electronic components. In addition, the issue of secondary fires where fires jump from one location to another is an important issue. The proposer is referred to the previously mentioned fire safety workshop at http://www.ncmr.org/events/firesafety.

Autoignition and explosion of in-situ propellants: Various propellants may be employed on extraterrestrial vehicles for maneuvering and orbit changes. In addition, need for expansion of this capability may well grow with time as we expand our exploration capabilities. The behavior of these materials has not been adequately characterized for the range of extraterrestrial conditions anticipated. In the case of monopropellants, such as hydrazine or unsymmetrical dimethylhydrazine (UDMH), the possibilities of autoignition or explosion of these propellants must be examined and strategies for minimizing the possibility of such events developed. In addition, in the case of oxygen generators (which already led to a major incident on Mir), safety issues need to be further examined.

Innovative combustor design approaches for conversion of fuel to useful work and/or electricity in a reduced gravity or microgravity environment: Volume and mass limitations on spacecraft substantially increase the need to extend energy conversion efficiency beyond the levels that are acceptable here on earth. Future exploration missions will need to store energy in quantities and durations that will exceed battery storage capability. Improved concepts are needed for power production and regenerative energy storage under extraterrestrial conditions. Of particular interest in this area are advanced fuel cells capable of utilizing various fuels (with likely involvement of reformers) and microcombustors, though other innovative approaches are not ruled out. How various possible engine cycles are influenced by reduced or microgravity is, of course, of major importance in the choice of ultimate approaches to be utilized.

Combustors for conversion of waste to energy and/or to recyclable products: Waste management in extraterrestrial habitats without frequent resupply is an important issue that has not been fully examined. Waste streams represent a biological hazard and a significant potential energy source. Reliable systems that can operate effectively in variable gravity and unusual environments are essential to long-duration mission viability. Issues include: water, oxygen, and nutrient recycling, stabilization, and volume reduction. Note that possible use of supercritical water oxidation (SCWO) processes may be considered under this topic.

Use of in-situ materials for production of propellants: Assuming our destination is Mars, the atmosphere present is mostly carbon dioxide. There are several approaches to using this in propulsion systems for lifting off from Mars or moving from place to place on Mars. The most direct approach, assuming that magnesium is available among the ores on Mars or is used in the lander structure and can be ground into a powder, is to design an engine that will burn the magnesium directly with CO_2 (numerous papers on this subject are available in the literature). A second approach is to break the CO_2 down into CO and O_2 using Zirconia CO_2 Electrolysis and burn the CO and O_2 directly, or, with the use of a water source, convert the CO into lower hydrocarbons such as methane for subsequent combustion with the O_2. All of these processes require technology development to reduce them to practice.

Development of chemical processing units for reduced and microgravity conditions: As an extension to the use of CO_2 and H_2O (or Hydrogen) in development of propulsion systems, another possibility is use of a sequence of chemical reactors to convert methane, nitrogen, and oxygenated hydrocarbons into various types of plastics for use on Mars. Again, considerable thought as to optimum approaches and technology development to permit use of such reactors under low gravity environments is required for accomplishment of such as-not-yet completely defined goals.

Advanced propulsion systems for interplanetary travel: Future exploration missions will include a wide variety of mission profiles that far exceed the current array of propulsion systems available to mission planners. Multiple restarts, in-situ propellants, partial-g operation, harsh environments, ultra-low thrust (micro-combustors), and long-duration reliability are only a few of the issues that must be considered.

This NRA also solicits innovative technology development activities that can further enable future combustion and chemical reactor investigations in space, largely through development of advanced diagnostics for quantifying temperature and species composition profiles in reacting systems, enabling more rigorous testing of analytical and numerical models.

It should be emphasized that future proposals are not limited to the topic areas discussed in this Appendix; extension to combustion topics not currently included in the Microgravity Combustion Program is strongly encouraged to permit us to broaden the program scope. As always, it is important that the proposer establish the study's clear microgravity relevance or relevance to OBPR space exploration goals, as delineated in the main body of this NRA.

In selection of future projects, while peer review for determination of technical merit and microgravity relevance will continue to be important in terms of providing a necessary condition for program selection, additional consideration will be given to how these programs fit within a framework developed for achievement of the goals of the discipline. In addition, it is very important that we coordinate our activities with those of other government agencies funding combustion research activities (requiring proposers to distinguish the unique reason(s) that NASA should fund their proposed work) and that we concentrate on transferring knowledge gained from our research to industrial use.

IV. HARDWARE AND FACILITY DESCRIPTIONS

A list of hardware, facilities, and diagnostic capabilities available or planned for use in the Microgravity Combustion program is given below. Detailed descriptions of the facilities and hardware may be found on the World Wide Web at

http://spaceresearch.nasa.gov/research_projects/nrahardware.html

Flight Hardware

The experimental hardware listed in this section is under development for flight on ISS. NASA anticipates additional future flight opportunities for investigations capable of using this hardware. To accommodate as many investigations as possible, the chamber inserts and diagnostics systems are being designed to be as modular as possible. This will allow PIs to share many major systems, reducing cost and time to flight.

A. ISS COMBUSTION INTEGRATED RACK (CIR)

B. MINI-FACILITY INSERTS

1. Multi-User Droplet Combustion Apparatus (MDCA)

2. Multi-User Solid Fuel Apparatus (FEANICS)

3. Multi-User Gaseous Fuels Apparatus (MGFA)

C. MICROGRAVITY SCIENCE GLOVEBOX

Ground-Based Facilities

Investigators often need to conduct reduced gravity experiments in ground-based facilities during the experiment definition and technology development phases. The NASA ground-based reduced-gravity research facilities that support the MRD combustion program includes two drop towers at NASA's Glenn Research Center (GRC) and a KC-135 aircraft that is based at the Johnson Space Center but may fly 6 campaigns per year from GRC. Each of these facilities and resources has different capabilities and characteristics that should be considered by an investigator to determine which are best suited for conducting combustion science research.

A. 2.2-SECOND DROP TOWER

B. 5.18-SECOND ZERO-GRAVITY FACILITY

C. REDUCED-GRAVITY AIRCRAFT

Diagnostics/Measuring Capabilities

NASA has adapted or developed a large number of diagnostic/measurement techniques for use in the Microgravity Combustion Research Program. Some of these techniques, including particle imaging velocimetry, laser light scattering, and Rainbow Schlieren Deflectometry, have already been demonstrated in flight. A brief list/description of techniques already in use or under development and possibly available for use in future programs can be obtained from Dr. Paul Greenberg (Glenn Research Center) at 216-433-3621.

Resources Requested from NASA (Form CF)

To aid NASA in evaluating the total annual cost of supporting proposed experimental research to be conducted at GRC, proposers are requested to complete and submit with their proposals a two-page form that can be obtained from http://microgravity.grc.nasa.gov/MSD/MSD_htmls/piinfo.html or from the Web site from which you obtained this NRA.

[Note: These two pages will not be counted against the maximum allowable page count for your proposal.]

V. NRA FUNDING AND SCHEDULE

The total amount of funding for this program is subject to the annual NASA budget cycle. Funds are not currently available for awards under the Combustion Science area of the Physical Sciences Research Division NRA. The Government's obligation to make award(s) is contingent upon the availability of appropriated funds from which payment can be made and receipt of proposals that NASA determines are acceptable for award under this NRA.

For the purposes of budget planning, we have assumed that the Physical Sciences Division will, in the combustion area, fund approximately 12 to 14 ground-based projects (at an average of about $120,000 per year) for up to 4 years and 1 or 2 flight definition proposals at an average of about $200,000 per year. The initial fiscal year (FY) 2004 funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts associated with the timing of the initiation of research relative to the government fiscal year. **It is particularly important that the proposer realistically forecast the projected spending timeline rather than merely assume an equal amount (adjusted for inflation) of requirements for each year.** The proposed budget for ground-based studies should include researchers' salaries, travel to science and NASA meetings (for a flight investigation, roughly eight meetings per year with NASA should be anticipated, though travel activity will vary over the development of the experiment), other expenses (publication costs, computing or workstation costs), burdens, and overhead. During subsequent years, NRAs similar to this one will be issued annually, and it is planned that funds will be available for additional investigations.

A complete schedule for the receipt and review of proposals to the Microgravity Combustion Science program is:

Notice of Intent Due:	**January 31, 2003**
Proposal Due:	**March 28, 2003**
Final Selections:	**September, 2003**
Funding commences: (dependent upon length of the procurement process)	**No sooner than October 2003**

VI. BIBLIOGRAPHY

Documents that may provide useful information to proposers are listed below:

The *Office of Biological and Physical Research Tasks and Bibliography*: http://research.hq.nasa.gov/taskbook.cfm

Proceedings of the Third International Microgravity Combustion Workshop, NASA Conference Publication 10174, April 11-13, 1995.

Proceedings of the Fourth International Microgravity Combustion Workshop, NASA Conference Publication 10194, May 19-21, 1997.

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In addition, considerable information on Glenn Research Center facilities, experiments, educational activities, missions, and services are available on the Web at http://microgravity.grc.nasa.gov.

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APPENDIX C
NRA 02-OBPR-03

FLUID PHYSICS: GROUND AND FLIGHT RESEARCH OPPORTUNITIES

I. INTRODUCTION

The Fluid Physics Program encompasses a broad spectrum of basic and applied research in physics and engineering science, including studies of heat and mass transfer processes, fluid dynamics, and the physics of complex fluids. NASA has supported research in microgravity fluid physics for over four decades. It is the aim of the Fluid Physics Program to use the combination of research on the International Space Station and on Earth to address a number of critical questions that are vital to NASA's future planetary and human exploration missions (e.g., propulsion, power and life support) and to enhance the nation's scientific and technical knowledge for applications on earth (e.g., development of photonic devices via colloids research, and improvement in industrial and agricultural processes by studying granular materials). This is consistent with OBPR's emphasis of two broad research categories: 1) human exploration of space (strategic research) and 2) intrinsic scientific importance and impact (fundamental research).

As one of NASA's five core Strategic Enterprises, the Office of Biological and Physical Research (OBPR) Enterprise will provide the research efforts required to obtain fundamental understanding and achieve scientific breakthroughs to enable safer, more efficient, more productive, and more affordable human exploration of space. The Space Studies Board of the National Research Council has concluded that extraordinary improvements need to be made in several areas for NASA to achieve exploration goals ("*Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies*," Space Studies Board, National Research Council, 2000). These areas include power generation/storage, space propulsion, life support, hazard control, material production/storage, and fabrication and maintenance. Fluid physics plays a significant role in many systems and subsystems related to these areas. The need for improved understanding of gravity dependent fluid phenomena to enable future space technologies and operations should be recognized as one of the primary opportunities of the discipline.

This extensive research program supports experimental and theoretical investigations in ground-based and space laboratories. Some investigators conduct experiments using the low-gravity test times available in drop-towers or research aircraft. These ground-based experiments, along with theoretical modeling, form the basis for most of our current understanding of the effects of gravity on fluid processes and phenomena and represent the bulk of the research program. Ground-based research has also been used to gain a rigorous framework to define experiments to be conducted in extended low gravity available on spacecraft in low-Earth orbit. Several flight experiments currently being built will be flown on the International Space Station (ISS). In many cases, research modules are being developed to accommodate multiple experiments and multiple users. The Physical Sciences Research Division will attempt, as a first priority, to accommodate proposed experiments on existing hardware, and proposers are encouraged to propose against existing flight hardware. Please see Section IV, Hardware and Facility Descriptions, for more information. Fluid physics investigations fall into the following sub-discipline areas: Complex Fluids, Interfacial Phenomena, Multiphase Flow and Heat Transfer, Dynamics and Instabilities, and Biofluids.

RESEARCH ANNOUNCEMENT OBJECTIVES

This NRA focuses and enhances the fluid physics program through the solicitation of

1) Experiment concepts defining and utilizing new instruments for space-based experiments in fluid physics with emphasis on research concepts that can be accommodated by compact and innovative instrumentation.

2) Ground-based experimental and theoretical studies leading to potential new flight investigations or enhancing the understanding of existing experiments in fluid physics with emphasis on research that will provide a new scientific foundation for innovative technologies required by future human and robotic space missions.

3) Interdisciplinary research projects utilizing teams of researchers from multiple disciplines (e.g., optics, materials science, combustion, biofluids, etc.) to advance technology, promote breakthrough research, and encourage technology transfer. A single researcher who is able to identify past work that has an interdisciplinary thrust may also propose citing all of his/her previous work that incorporates the interdisciplinary approach. Interdisciplinary proposals should clearly identify key personnel and their fields of expertise. It must be clearly stated who the Principal Investigator and the lead institution are and how the effort will be integrated. Management structure, goals, and cooperation with the research community to facilitate the transfer of technology must be evident in the proposal.

In support of the goal of human space exploration through science and technology, individuals participating in the research program are encouraged to help foster the development of a scientifically informed and aware public. The research program is an opportunity for NASA to enhance and broaden the public's understanding and appreciation of the value of research in the environment of space. Therefore, all participants in this NRA are strongly encouraged to promote general scientific literacy and public understanding of the microgravity environment and fluid physics through formal and/or informal education opportunities. Where appropriate, supported investigators will be required to produce, in collaboration with NASA, a plan for communicating the value and importance of their work to the public.

SPECIAL NOTE TO SPACE FLIGHT PROPOSERS: It is recommended that you include an attachment describing your flight experiment concept, the implementation of your experiment, and the level of development required for any important instrumentation. This information is helpful to assess the maturity of your experiment by a review team of engineers experienced in development of space flight hardware.

II. PROGRAM RATIONALE

Fluid Physics has a crucial role in supporting enabling technologies for long-duration human space flight. Strategic research is needed to support several technologies such as power generation and storage, space propulsion, life support, and materials production and storage.

Fluid physics is the study of the properties and motions of liquids and gases. Such studies arise from nature (e.g., in meteorology, oceanography, and living plants or animals) and technology (e.g., in biological, chemical and material processing, and fluid systems). Fluid phenomena span scales that range from nanometers to light years and by their ubiquity constitute one of the fundamental areas of science and engineering. The need for better understanding of fluid phenomena has created a vigorous, multi-disciplinary research community in fluid physics, whose continuing growth has been marked by the steady emergence of new fields of relevance in both basic and applied science. Areas of technological and ecological importance such as global atmospheric change, groundwater pollution, oil production, and advanced materials manufacturing often rely for their progress on advances in fluid physics. Scientists studying basic problems from chaotic systems to the dynamics of stars also turn to fluid physics for their models. Through the history of fluid physics, theory and experiment have maintained a synergetic relationship in building scientific knowledge. In recent years, research in fluid physics has been at the forefront in applying large-scale computational techniques to physical problems. The continuing advance of high-performance computing will drive new theoretical insights, which will spur a new generation of experimental fluid physics.

Gravity strongly affects many phenomena of fluid physics that drive motions, shape boundaries, and compress fluids. Further, the presence of gravitational forces can mask effects of other forces that are ever present but comparatively small.

Microgravity research encompasses the phenomena related to gravitational fields (or equivalent accelerations with respect to inertial frames) whose magnitudes are but a small fraction of Earth's gravity. Fluid physics has a unique role in the NASA microgravity science program. Gravitational physics deals directly with the existence of gravity. Other scientific disciplines are interested in developing the potential of the microgravity environment as a research tool and hope to create controlled conditions of fluid flow and heat and mass transport in specialized circumstances, e.g., the growth of protein crystals, the solidification of a molten semiconductor, or the burning of liquid fuels. The goal of much of fluid physics research is simply to comprehend fundamental physical phenomena. In doing this, fluid physics contributes to seemingly distant fields of research by providing a fundamental framework of principles and basic understanding for flow and transport that specialists in other disciplines can apply to their problems.

III. RESEARCH AREAS OF INTEREST

OBPR is emphasizing two broad research categories: 1) human exploration of space (strategic research) and 2) intrinsic scientific importance and impact (fundamental research). The Microgravity Fluid Physics Program readily encompasses both areas.

Strategic Research is research and technology needed to enable long-duration human space flight. Such missions may include Mars exploration or even deep space exploration that would require, for example, advanced power, propulsion, life support systems, and material production. The space technology required for these future propulsion, power, and life support systems cannot solely rely on Earth gravity based designs. Fluid systems behave differently in space, especially when two or more phases are present. For example, in microgravity, the safe upper limit for pool boiling changes, the pressure drop and heat transfer are altered in two-phase flow, and the liquid in a propellant tank reorients based on surface tension, surface wetting, and container geometry. Subsystems that will be affected include boilers, condensers, liquid-vapor separators, two-phase radiators, heat pipes, cryogenic storage tanks, etc. Please see "*Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies*," Space Studies Board, National Research Council, 2000. Examples of research topics include: Pool and Flow Boiling, Gas-Liquid Flow through Packed Beds, Fluids Handling, Miniaturized Chemical and Physical Process Equipment (applicability for space in-situ resource utilization applications), Granular Flows, Dust Flow and Particulate Control, and Fluid Physics aspects of Biomedical Processes in Space (bone loss, orthostatic intolerance, cephalad fluid shift, and development of countermeasures).

Fundamental research includes investigations that use the microgravity environment to study the effects of nongravitational forces on fluid behavior in order to expand the current knowledge of understanding or to promote innovation in terrestrial technologies. Examples of research topics include Morphology and Rheology of Colloids, Surface Tension on Fluid-Fluid Interfaces and Fluid-Fluid-Solid Trijunctions, Transport Phenomena Involving Charged Fluid Interfaces, Capillary Phenomena Affecting Drops and Bubbles, Non-Newtonian Behavior of Complex Fluids, Nanoscale Fabrication and Self Assembly Processes (often occurring in the fluid phase).

We are currently funding 23 flight- and 101 ground-based investigations encompassing both experimental and modeling activities. They are divided into the following areas. (Most areas include both Strategic and Fundamental research.)

COMPLEX FLUIDS

Complex fluids comprise a large class of soft materials, which often consist of mesoscale supramolecular aggregates, ranging in size from ~1 nm to ~1 micron. Their physical properties are determined by the interplay of entropic and structural intermolecular forces and interfacial interactions. Examples are microemulsions, foams and suspensions of colloids or microgels, liquid crystals, biological membranes, the intracellular macromolecular scaffolds of cytoskeleton, and the extracellular matrix. The highly interdisciplinary field of complex fluids thus bridges the gap between synthetic and living materials. Aside from the scientific challenges, complex fluids have a broad range of industrial, biological, and environmental applications. Examples are soaps, polymeric lubricants and emulsifiers, and drug delivery systems. Brownian motion keeps these mesoscopic particles in suspension even in the presence of gravity, but the relatively small sedimentation that normally occurs can have profound effects on ordering, crystallization, and equilibrium structures. Near absence of gravitational force in space, therefore, provides an ideal laboratory for studying long-term equilibrium properties of complex fluids. In the case of hard sphere colloids, this has been demonstrated by experiments conducted in space under NASA's microgravity research program. Experiments conducted in space show formation of dendritic crystals and crystallization of colloidal samples that stay in the glass phase for years on Earth. Also, phase separation tests from the Physics of Colloids in Space experiment, conducted on the ISS, are the first to follow the process from its microscopic beginnings to the final, fully separated state. Use of this hardware is encouraged and available to the research community. Please see Section IV, Hardware and Facility Descriptions: Physics of Colloids in Space Facility. Some specific examples of complex fluids research areas are provided below.

1. Colloids and Suspensions: Colloids are used to study phase transitions and fluid behavior and can be used to model atomic systems.
2. Nanoscale Fabrication in the Fluid Phase: Self-assembly of colloids offers a direct route to fabrication of nanoscale devices with controllable structure and properties.
3. Granular Mechanics: Granular media represent an interesting class of materials that can exhibit a spectrum of complex flow behavior, ranging from solid-like to gas-like.
4. Non-Newtonian Fluids: Complex fluids such as polymers, liquid crystals, slurries, and suspensions exhibit nonlinear material response to imposed deformations.
5. Near-Critical Point Fluid Behavior: A pure fluid near its liquid-vapor critical point exhibits universal and interesting properties. For example, a simple fluid such as Xenon is known to exhibit non-Newtonian visco-elastic behavior near its critical point.

Strategic research in this area includes granular flows, dust flow, and particulate control. Applications of the research are: material production and storage (mining, volatilization and condensation including lunar volatiles and water ice extraction, material handling and transport), and construction and maintenance (site preparation, concreting, direct manufacturing fabrication of components and structural elements from raw or processed materials).

INTERFACIAL PHENOMENA

Understanding behavior of fluids at a solid-liquid-gas tri-junction as well as liquid-gas/vapor interfaces is not only a subject of scientific curiosity but also of great technological interest. Many natural and technological processes and phenomena, such as coating and painting of surfaces, morphological stability of interface during crystallization, oil recovery from shale, and liquid mediated chemical reactors, rely on the fluid mechanics of the solid-liquid-gas tri-junction. Gravity, on Earth, tends to overwhelm the effects of surface tension force except in a very thin layer of fluid in the vicinity of the solid-fluid interface. In microgravity, the region influenced by surface tension is magnified considerably, allowing one to probe the characteristics of this region with much greater precision and insight. Also, the behavior of liquid-vapor/gas interface in microgravity is a subject of great interest for engineers dealing with liquid management in partially filled tanks in space. Examples include

1. Capillary Phenomena: Earth gravity overwhelms the effects of capillary forces except for a thin layer near the solid-fluid interface. In microgravity, surface tension can control the shapes of liquid bodies of even large scale, leading to configuration changes that can be important in the drainage of fuel tanks and generally in the area of fluid handling.
2. Solid-Liquid Interactions: Contact-line dynamics of fluid-fluid-solid tri-junctions can control coating of solid surfaces, cooling of hot surfaces, and behavior of vapor bubbles in nucleate boiling.
3. Coalescence and Aggregation Phenomena: Numerous phase-separation processes rely on coalescence or aggregation of dispersed phases to form continuous phases. Boiling, condensation, foam drainage and coarsening formation, and (Ostwald) "ripening" of solid precipitates are familiar examples.

4. Drops and Bubbles: The microgravity environment allows the use of sample levitation methods to study the capillary dominated phenomena affecting the dynamic and static behavior liquid drops in air and gas/vapor bubbles in liquid.

Strategic research in this area includes surface-tension-related phenomena that may dominate fluid behavior. For example, the handling and storage of cryogenic fluids may entail the use of vanes, wicks, and screens that rely on capillarity to control the location of the fluid. Heat pipes and capillary pumped loops also depend on surface tension effects. Condensation, evaporation, boiling, and sublimation are influenced by both gravity and interfacial forces.

MULTIPHASE FLOW AND HEAT TRANSFER

Due to relatively large density differences between phases, gravity tends to exert a controlling influence on multiphase flows and phase changes. Microgravity behavior of such systems often differs markedly from normal-gravity behavior. Many advanced concepts for power generation and energy storage, space propulsion, thermal management, and environmental control and life support in space rely on multiphase flow and phase change; accordingly, understanding of multiphase flow and phase change in microgravity is of critical importance for NASA's space exploration needs (strategic research). Consequently, NASA is interested in supporting a space experiment on two-phase flow (preferably with heat transfer).

1. Flow Regimes and Regime Transitions: Multiphase flows normally configure themselves into distinctive flow regimes in which the various phases are non-uniformly distributed across the duct through which they flow.
2. Pool and Flow Boiling: Nucleate boiling is one of the most efficient heat transfer mechanisms, not only on Earth, but also for space applications where the size and mass of the equipment are critically constrained.
3. Condensation: Devices such as capillary pumped loops, loop heat pipes, and two-phase radiators depend critically on condensation.
4. Gas-Liquid Flow through Packed Beds: Gas-liquid two-phase flow through a fixed bed of particles occurs in many unit operations of interest to the designers of space-based and terrestrial equipment.

Strategic research encompasses this entire category. NASA engineers have often avoided the use of multiphase systems and processes in spacecraft and satellites because they lack a basic understanding of multiphase flow and heat transfer phenomena in reduced-gravity environments. This has prevented the deployment of efficient and high-power-density active systems that otherwise might have been used for NASA's missions. Nevertheless, it appears that the reliable operation of numerous phase-change systems for propulsion, power production, and life support will be required for long-duration missions. Thus, multiphase flow and heat transfer technology is considered to be a critical and potentially revolutionary technology. It is required to better understand the performance of multiphase systems in space and to provide the basis for the development of accurate computational capabilities. There is a continuing need for experimental microgravity data and appropriate empirical correlations as well, since some physical phenomena and design issues may go beyond current, and anticipated near-term, computational capabilities. Applications include power generation and storage (solar power systems, chemical power systems, nuclear power systems, batteries; fuel cells), space propulsion (chemical rocket, nuclear thermal rocket, nuclear electric propulsion, solar thermal), and life support (air revitalization, temperature and humidity control, water recovery).

BIOFLUIDS

Biofluids is an intersection of fluid physics and biology. Fluid mechanics and transport processes play a critical role in many biological and physiological systems and processes. An adequate understanding of the underlying fluid physics and transport phenomena can provide new insight and techniques for analyzing and designing systems that are critical to NASA's mission. Applications derived from biology and physiology can enrich the fluid mechanics and transport phenomena research performed by investigators of the microgravity fluid physics community. Some examples are

1. Physiological Systems: The microgravity environment modifies vascular fluid distribution on a short time scale due to the loss of hydrostatic pressure, and on a longer time scale due to the shift of intercellular flows. This fluid shift could modify transport processes throughout the body.
2. Cellular Systems: It has been shown that removal of gravity can impact cell differentiation, thus providing an important tool in the search for microenvironmental cues (bioactive molecules, local forces including adhesion), which contribute to organ assembly and tissue-specific differentiation.
3. Biocrystals and Biomaterials: Fluid physics and transport phenomena play a key role in determining the morphology of biocrystals. In normal gravity, buoyancy-driven convection can alter the concentration fields and resulting properties of crystalline structures. The microgravity environment allows diffusion-controlled processes to govern such phenomena under certain circumstances.
4. Biochip Research: The heart of biochip devices is a miniaturized microfluidics system capable of moving liquids containing various reagents and samples to and from holding regions. Integrating on-board valves, mixing, and other standard fluid handling devices together with on-board detection systems have enabled rather complex, analysis-specific systems to be developed.

Related research in life support and monitoring technologies is also being solicited through the Advanced Human Support Technology (AHST) Program of the Bioastronautics Division. Collaborative research in these areas is encouraged. Examples include 1) development of miniaturized sensors that can sense chemical and microbiological contaminants in air, water, and on surfaces to help maintain a safe environment for astronauts, and 2) continued development of life support systems are essential to the viability of future long-duration human space flight and include air revitalization, water recycling, solid waste processing, and subsequent resource recovery, and food processing and biomass production. More details of current research can be found at the following Web site:

http://research.hq.nasa.gov/taskbook.cfm

AHST solicitations are typically released in the early part of the calendar year. Please visit the following Web site: http://research.hq.nasa.gov/code_u/future.cfm

Strategic research in this area includes life support and monitoring technologies mentioned above.

DYNAMICS AND INSTABILITIES

Buoyancy is one mechanism by which Earth's gravity can exercise a strong influence on flow. Many well-known flow instabilities, such as Rayleigh-Bénard instability, are controlled by gravity. When gravitational force is removed, other forces such as surface tension can exercise significant influence on many flows. The Marangoni-Bénard instability is an example of surface tension controlled phenomena. This subdiscipline of fluid physics deals with a broad category of flow phenomena where the absence of gravity can produce new flow physics.

1. Thermocapillary and Solutocapillary Phenomena. When a fluid-fluid interface is subjected to a tangential gradient of temperature and/or species concentration, shear stresses are created in the interface, which drive bulk motions. Such surface effects can control the migration of droplets in bulk or along solid surfaces.
2. Electrokinetics and Electrochemistry. Electrokinetics concerns transport phenomena involving charged fluid interfaces and their associated diffuse layer of space charge.
3. Geophysical Flows: Accurate prediction of weather is an everyday concern, with enormous ramifications for most human activity. It is the coupled ocean-atmosphere fluid system that controls the weather and its long-term trend, the climate. The fluid mechanics of this system falls in the realm of geophysical fluid flows.

Strategic research in this area includes fluid-fluid interface dynamics, fluid-solid interface dynamics, inertia effects, and viscous effects that can be applied to, for example, two-phase flow in multi-channels.

TECHNOLOGY DEVELOPMENT

This NRA also solicits innovative technology development activities that can a) enable the human exploration of space (strategic technologies) and b) improve future fluid physics experiments in space (e.g., through advanced diagnostic equipment). Successful proposals will aim to bring technology from the conceptual stage (readiness level 0 to 1) through to feasibility verification at the prototype laboratory stage (readiness level 3 to 4).

Regarding the human exploration of space, NASA is interested in technology developments that improve low-gravity fluid-thermal control systems, low-gravity fluid behavior in advanced power and propulsion systems, and low-gravity fluid management in environmental control and life support systems, etc. Major systems and associated technologies and operations that are of critical importance and may have significant gravity-dependencies include

- **Power Generation and Storage** (Solar Power Systems, Chemical Power Systems, Nuclear Power Systems, Batteries, Fuel Cells)
- **Space Propulsion** (Chemical Rocket, Nuclear Thermal Rocket, Nuclear Electric Propulsion, Solar Thermal, Solar Sail, Laser Thermal, Laser Sail)
- **Life Support** (Air Revitalization, Temperature and Humidity Control, Trace Biological, Chemical and Particulate Contaminant Control, Water Recovery, Solid Waste Management, Food Production)
- **Hazard Control** (Fire Protection, Spill Cleanup, Protection from Chemical and Biological Contamination)
- **Material Production and Storage** (Mining; Volatilization/Condensation including lunar volatiles and water ice extraction; Material Handling and Transport; Concentration and Beneficiation of Feedstock; Fluid-based Chemical Processing such as electrochemical processing, molten metal electrolysis, radio-frequency processing of materials, oxygen production; Cryogenic Storage)
- **Construction and Maintenance** (Site Preparation, Concreting, Direct Manufacturing such as computer-controlled layer deposition techniques, Fabrication of Components and Structural Elements from Raw or Processed Materials, Casting, Sintering, Composite Materials, Joining Methods in Space)

Some selected subsystem technologies of critical importance to the above major systems, technologies and operations that may have significant gravity-dependencies include

- **Power Generation & Storage**: Rankine Cycle Boiler, Two-phase Radiators, Proton-Exchange Membrane Fuel Cells, Capillary-Driven, Two-phase Devices (e.g. heat pipes), Vapor-Pressure Pumped Loops, Alkali Metal Thermal-to-Electric Conversion
- **Space Propulsion**: Nuclear Fission Reactor, Cryogenic Storage System, Radiator System, Solar Collector, Rankine Cycle Boiler, Gas/Vapor Turbines, Liquid Pumps, Compressor, Rankine Cycle Condenser, Propellant Vaporizer, Switch Gear and Electric Power Conditioning
- **Life Support**: Heat Exchangers, Condensers, Liquid-vapor Separators, Distillers, Boilers, Storage Tanks, Choppers/grinders
- **Hazard Control**: Electrical System Fault Diagnostic and Response System, Smoke Detectors, Fire Extinguishers, Post-fire Cleanup Systems, Particulate Control
- **Materials Production and Storage**: Condensers, Fluidized-bed Reactor, Gravity Collection Bins, Pipes, Furnaces, Refrigerated Tanks, Conveyors
- **Construction and Maintenance**: Grinders, Blenders, Mixers, Liquid Feeders, Conduction/ convection/sintering Furnaces, Welders

IV. HARDWARE AND FACILITY DESCRIPTIONS

The Physical Sciences Research Division (PSRD) is pursuing a program for the development of International Space Station payloads that can be configured (or reconfigured) to accommodate multiple users. This evolutionary program is expected to meet the science requirements of increasingly sophisticated microgravity investigations and to permit the eventual development of experiment payload technologies for research throughout the era of the ISS.

A list of hardware, facilities, and diagnostic capabilities available or planned for use in the microgravity Fluid Physics program is listed below. Detailed descriptions of those facilities is provided on the following Web site:

http://spaceresearch.nasa.gov/research_projects/nrahardware.html

Current and Planned Flight Hardware

A. ISS FLUIDS INTEGRATED RACK (FIR)

B. FIR EXPERIMENT HARDWARE

1. Light Microscopy Module (LMM)
2. Granular Flow Module (GFM)
3. Microgravity Observations of Bubble Interactions (MOBI)

C. PHYSICS OF COLLOIDS IN SPACE FACILITY (PCS)

D. AERODYNAMIC FLUID PHYSICS RESEARCH FACILITY

E. MECHANICS OF GRANULAR MEDIA APPARATUS (MGMA)

F. ISS MICROGRAVITY SCIENCE GLOVEBOX

G. GLOVEBOX EXPERIMENT HARDWARE

1. Boiling Experiment Facility (BXF)
2. Shear History and Extensional Rheology (SHERE)
3. Ultraviolet-Visible-Infrared Spectrophotometry (UVIS)

H. SPACE DRUMS FACILITY or Space-Dynamically Responding Ultrasonic Matrix System (DRUMS®)

I. NASDA FLUID PHYSICS EXPERIMENT FACILITY (FPEF)

J. ESA FLUID SCIENCE LABORATORY (FSL)

K. DISPOSITIF POUR L'ETUDE DE LA CROISSANCE ET DES LIQUIDES CRITIQUES (DECLIC)

Ground-Based Facilities

Investigators often need to conduct reduced gravity experiments in ground-based facilities during the experiment definition and technology development phases. The NASA ground-based reduced gravity research facilities that support the fluid physics program include two drop towers at the Glenn Research Center (GRC): the 2.2-Second Drop Tower and 5.18-Second Zero-Gravity Facility. A variety of specialized test rigs are available to conduct a wide range of microgravity fluid physics research: Two

Phase Flow Test Rig, Computational Lab, Motion Analysis and Object Tracking System, and Complex Fluids Cell Flight Hardware Lab.

Fluid Physics Diagnostic and Measurement Capability

NASA has adapted or developed a number of diagnostic and measurement techniques for microgravity fluid physics research that is available for research on Earth and could possibly be modified for flight research. Examples include: Laser Tweezers, Surface Light Scattering Hardware, Interferometry, Velocimetry, Birefringence, Diffusing Wave Spectroscopy (DWS), Rainbow Schlieren Reflectometry, Flow Pattern Visualization, and Liquid Surface Temperature and Vapor Phase Concentration Measurements.

V. NRA FUNDING AND SCHEDULE

The total funding for this program is subject to the annual NASA budget cycle. Funds are not currently available for awards under the Fluid Physics area of the Physical Sciences Research Division NRA. The Government's obligation to make award(s) is contingent upon the availability of appropriated funds from which payment can be made and receipt of proposals that NASA determines are acceptable for award under this NRA. Approximately 30 proposals from those judged to be highly meritorious will be funded at an average of $110,000 per year for up to 4 years. Most selections will be ground-based, but some flight definition selections are planned. Also, if the proposal is of high value and receives an excellent review, NASA may consider higher funding levels for such proposals. The initial fiscal year (FY) 2005 funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts. It is particularly important that the investigator realistically forecast the projected spending timeline rather than merely assume an equal amount (adjusted for inflation) of requirements for each year. Specifically, the resources required for the first year should not be overestimated. The proposed budget for ground-based studies should include salaries, equipment, supplies, travel to science and NASA meetings, other expenses such as publication or computing costs, and indirect costs. All proposals submitted in response to this Announcement are due on the date and at the address given below by the close of business (4:30 p.m. EST). NASA reserves the right to consider proposals received after this deadline if such action is judged to be in the interest of the U.S. Government. A complete schedule of the review of the proposals is given below:

Notice of Intent Due: **October 10, 2003**

Proposal Due: **December 10, 2003**

Final Selections: **June 2004**

Funding Commences: **No sooner than November 2004**
(dependent upon actual selection and procurement process)

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APPENDIX D
NRA 02-OBPR-03

MICROGRAVITY FUNDAMENTAL PHYSICS: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

I. INTRODUCTION

Fundamental physics is the study of the most basic principles of nature. Many examples exist where tests of these basic principles can be performed better in the environment of low-Earth orbit. Over the last decade, NASA's Microgravity Fundamental Physics program has included research in the fields of Laser Cooling and Atomic Physics (LCAP), Low Temperature Condensed Matter Physics (LTCMP), and Gravitational and Relativistic Physics (GRP).

The overarching program goal is to unlock mysteries of the Universe by exploring the frontiers of physics using laboratories in space. Ground-based research is used to gain a preliminary understanding of phenomena, and to define experiments to be conducted during extended exposure to the space environment using spacecraft in low-Earth orbit. The ground-based studies form the foundation for our research program and serve as the intellectual underpinning of the investigations to be conducted in space.

The primary focus for future research activities in this area will be on flight opportunities using International Space Station research instruments. NASA is currently studying the development of modular research instruments that can be configured (or reconfigured) to accommodate multiple experiments and multiple users. This approach is envisioned as an evolutionary program with the objectives of providing experimental data in response to increasingly sophisticated science requirements, and of permitting the evolution of experimental approaches and techniques for scientific investigations throughout the era of the International Space Station.

While research into fundamental physical properties of nature is still considered to be the most important component of our research program, there is also an opportunity with this solicitation to pursue interdisciplinary research and to develop technology aimed at enabling and supporting safe and efficient human exploration of space.

II. PROGRAM RATIONALE

This NRA is intended for research activities in fundamental physics that can utilize the unique environment of space in an important way.

Problems in physics where the space environment can be beneficial include those sub-fields where interactions are weak; where extremely uniform samples free from hydrostatic compression are required; where objects must be freely suspended and their acceleration must be minimized; where space offers a unique environment not available on the Earth; and where the mechanical disturbances unavoidably present in Earth-bound laboratories must be eliminated.

One category of experiments can benefit either from the free-fall environment available in space, or from the use of variable gravity as a parameter whose change may lead to the elucidation of otherwise hidden properties and phenomena. The physics of critical phenomena is prominent among the issues that have been investigated so far under free-fall conditions. A free-fall environment plays an important role in these investigations because the closeness of approach to a critical point in the Earth-bound laboratory is limited, not by the skills of the experimentalist, but rather by the uniformity of the sample that is spoiled by hydrostatic pressure variations.

A second category of investigations requires atoms to be retained virtually without motion and distortion in a cavity for extended time intervals. On Earth, the length of time that the atoms can be held in the cavity is limited by the gravitational acceleration. Studies of laser-cooled atoms exemplify experiments in this category.

A third category of studies includes those that can benefit from the opportunity to virtually eliminate all mechanical disturbances in space. For example, such disturbances limit experiments based on proof-mass techniques to probe fundamental questions in gravitational and relativistic physics, where the positions of objects relative to each other must be maintained and measured with a resolution unobtainable in the gravitationally noisy environment on Earth.

A fourth category of investigations benefit not from the free-fall of orbital flight, but rather from other aspects of the space environment, such as the availability of new space-time coordinates, different gravitational potentials, or environmental effects peculiar to space.

Space experiments offer an opportunity to extend a set of measurements beyond what can be done on Earth, often by several orders of magnitude.

This extension can lead either to a more precise confirmation of our previous understanding of a problem, or it can yield fundamentally new insight or discovery. NASA maintains a relatively large number of ground-based investigations, together with a relatively smaller number of space-based projects. A vigorous ground-based program will identify the experiments that are most worthy of consideration for space. Thus, it is expected that the space experiments are a natural outgrowth of the ground-based program. A space experiment should be performed on Earth to its maximum potential before it is developed for space. Ground-based studies can determine whether a highly complex experiment would be successful when conducted in space. Ground-based studies also ensure that the value of the science knowledge to be gained by a space experiment cannot be greatly diminished by future ground-based experiments.

With this solicitation, NASA intends to select both flight-definition and ground-based research investigations. Approximately 3 to 4 innovative flight-definition investigations for the ISS in the 2009 timeframe are targeted for support. Approximately 10 to 15 ground-based investigations covering experimental studies with the potential for future flight, theoretical studies to support current or planned flight experiments, and investigations aimed at developing research-enabling technology will be supported. The actual numbers of selections will be influenced by the response from the scientific community.

III. RESEARCH AREAS OF INTEREST

NASA is currently funding approximately 65 investigations in fundamental physics. About 4 in every 5 investigations are ground studies, with the remainder being either flight or flight-definition studies. Both experimental and theoretical activities are being supported. The main sub-disciplines and study areas currently supported in the program are described below.

Laser Cooling and Atomic Physics: Fundamental forces and symmetries, Bose-Einstein condensation and quantum gases, and atomic interferometers.

Low Temperature and Condensed Matter Physics: Critical phenomena, solid-fluid interfaces, non-equilibrium systems, superfluid hydrodynamics, and melting-freezing of quantum crystals.

Gravitational and Relativistic Physics: Tests of theories and gravitation, test of Einstein's Equivalence Principle, and tests of the inverse square law of gravity.

More detailed information about the current program can be found in accessible Web site references cited in the Bibliography section.

The Fundamental Physics Discipline Working Group has carefully considered and advised NASA on future research directions for this discipline. NASA has considered these recommendations in establishing the future program directions description shown below. In addition, NASA will consider proposals in research areas not described in this announcement, where the space environment offers a significant advantage to researchers in helping us understand and describe the universe and the physical laws governing its behavior.

With this solicitation, NASA is interested in selecting innovative flight-definition investigations that can take advantage of future opportunities aboard the International Space Station; ground-based experimental investigations with a potential for future flight; theoretical investigations supporting current or future flight experiments; interdisciplinary investigations; and development of advanced technology. The description of the research hardware under development can be found in Section V.

LASER COOLING AND ATOMIC PHYSICS

Fundamental Forces and Symmetries. Almost every precise measurement made in science ultimately traces back to a time or frequency measurement. NASA is currently developing space clocks with one to two orders of magnitude better precision than existing ground clocks by taking advantage of the free-fall environment on the ISS. At the heart of the atomic clock is a measurement of a carefully chosen energy level splitting within the atom. These splittings are nature's own reference “standards" and are sensitive to subtle aspects of fundamental forces and to basic symmetries of nature. Ultra-precise atomic measurements can make important contributions to answering questions ranging from predictions of string theories and M-theory, search for the possible variation of fundamental constants, and an examination of the robustness of the fundamental symmetries that underlie the basis of the Standard Model. Use of space can play a vital role in exploring these and related problems.

Bose-Einstein Condensation (BEC) and Quantum Gases. Recently, dramatic advances in the condensation of large numbers of atoms into the BEC state and into a degenerate Fermi gas state have been made, resulting in new insight into quantum transport phenomena. As lower and lower temperatures are achieved using evaporative cooling, gravitational limitations are emerging. For example, the energy bias introduced by the gravitational field reduces the efficiency of evaporative cooling, which is the final cooling stage used to pass into the BEC phase. High-precision investigations of freely expanding sub-nanokelvin condensates and very dilute condensates will become increasingly difficult in Earth-based laboratories due to the gravitational acceleration. BECs can be used to study quantum vortices, which together with the study of Fermi degenerate fluids allow laboratory study of problems related to astrophysics. In a free-fall environment, the ability to study new aspects of the continuous, pulsed, and solitonic matter wave lasers is also enhanced.

Atomic Interferometers. Reaching far beyond the initial goal of demonstrating the interference of matter waves of massive, complex particles, the atom interferometer is now used to realize high performance rotation sensors (gyroscopes) and gravity gradiometers that provide unprecedented sensitivity. These techniques can also be applied to the study of fundamental problems such as improving our knowledge of the gravitational constant G, and searching for possible violations of Einstein’s general relativity and other metric theories of gravity using quantum mechanical systems. The elimination of disturbing gravity effects in space in turn allows significant improvements for many interferometer experiments.

LOW TEMPERATURE AND CONDENSED MATTER PHYSICS (LTCMP)

Critical Phenomena. The physics of critical-point systems is extremely diverse but, at the same time, it is unified through the framework of the Renormalization Group (RG) theory. Two important critical points that have proved to be excellent test systems for the RG theory are the superfluid transition in liquid helium and the liquid-gas critical point. A third important test system is the tricritical point in ^{3}He-^{4}He mixtures. As well, room temperature critical point experiments concerning the viscosity or the turbidity of fluids near liquid-gas critical points can provide new information about the interactions of the density fluctuations.

Solid-Fluid Interfaces. One important issue in condensed matter physics concerns the nature of the interface between solids and fluids. The boundary conditions that prevail at this interface have an influence on macroscopic phenomena, but the microscopic aspects of the system near the boundary are difficult to study. Because the fluid near a critical point has a boundary layer of macroscopic thickness, a critical fluid system that is confined can be used to improve the study of boundary effects. Areas of proposed study can include the influence of boundaries on thermodynamic properties, the influence of boundaries on transport properties, and the critical Casimir force. Both one-dimensional (fluid in tubes) and two-dimensional (fluid between planes) confinements can be studied.

Non-equilibrium Systems. Nature displays many non-equilibrium systems subject to constant change and transformation to other states of matter. Yet most studies of physics consider the idealized case of equilibrium. The statistical dynamics of many-particle systems in a non-equilibrium condition is an important field of physics that is far from being well developed and well understood. The criticality of a system can be exploited to explore extreme non-equilibrium conditions where transport becomes a nonlinear phenomenon.

Superfluid Hydrodynamics. A number of highly interesting experiments in superfluid hydrodynamics exist that can be carried out under free-fall conditions. One class addresses the intrinsic nucleation problem for quantized vortices in superfluid helium. In yet another experiment, a superfluid helium drop could be rotated rapidly to observe the deformation from the spherical shape against the force of surface tension. Creation and suspension of drops offers other classes of experiments studying collisions of drops and coalescence. At low enough temperatures, hydrogen and ^{3}He also behave as quantum fluids (or solids), and perhaps even as superfluids, providing new scientific insight and new types of phase transitions to study.

Melting-Freezing of Quantum Crystals. First-order phase transitions involving melting and freezing processes in quantum crystals have long been of fundamental interest to physicists. Prominent among the fundamental issues of interest are the mechanisms involved in the transfer of atoms from liquid to solid and vice-versa, nucleation of a new phase within an existing one, and diffusive and ballistic mass transport. In addition, an important aspect of crystal formation involves the phenomena that govern the evolution of crystal shapes, that is, the so-called roughening transitions and associated phenomena.

GRAVITATIONAL AND RELATIVISTIC PHYSICS

Tests of Theories of Gravitation. Tests of Einstein's theories of relativity and of other metric and non-metric theories of gravitation serve as a foundation for understanding how matter and space-time itself behave at both large and small length scales and under extreme conditions. The free-fall environment of space, the use of low-temperature techniques and precise superconducting instruments, the application of laser cooling and mass interferometer techniques, and the use of high-precision frequency standards all offer opportunities to perform improved tests of these theories significantly beyond what is possible on the ground.

Test of Einstein's Equivalence Principle (EEP). The EEP provides a foundation for all metric theories of gravity and is important to the quest for unifying all fundamental forces of nature. Despite the beauty and profundity of Einstein's theory and the success of the Standard Model, our present understanding of the fundamental laws of physics has shortcomings. At present, no realistic theory of quantum gravity exists. The Standard Model suffers from unresolved problems concerning the violation of the Charge-Parity symmetry between matter and antimatter and the various unexplained mass scales. Suggested solutions to these shortcomings typically involve new interactions that could manifest themselves as violations of the EEP. The construction of a “Grand Unified Theory” of weak, electromagnetic, and strong interactions may include the existence of a supersymmetry between fermions and bosons. This framework suggests the existence of new interactions beyond those of the Standard Model. One of the most important predictions based on supersymmetry is the existence of the axion, which mediates a force between mass and intrinsic spin. Confirmation of this prediction would have a major impact on our understanding of the Universe. In a space environment, the weak or strong equivalence, local Lorentz invariance, and local position invariance aspects of EEP can be tested independently at high precision to search for indications of such new features of physical law. Measurements of the gravitational red shift also test important aspects of the local position invariance part of the EEP and are tied to the possible spatial variation of the fine-structure constant α, a parameter central to quantum electrodynamics.

The Inverse Square Law of Gravity. Another way that new interactions can manifest themselves is as Yukawa-type interactions of a certain range. Some theories, including string theories, have suggested that the new interactions will appear at short range, perhaps below a millimeter. Precise measurements testing the inverse-square law aspect of gravity at short range will search for such new forces, testing predictions of string theory, and can also test for the existence of axions.

INTERDISCIPLINARY RESEARCH AND TECHNOLOGY

Interdisciplinary Research. Physics techniques and technologies can be applied to address open questions in the physical, biological, and life sciences and to enable space exploration activities. These techniques can also be used to support the detection of life elsewhere in the Universe. Examples of support to space exploration activities include ultra-high performance geodesy studies, geological studies related to planetary resources, investigation of planetary dynamics, and studies of the Earth's oceans.

Technology Development. This NRA also solicits innovative technology development activities that can enable future fundamental physics investigations in space. Successful proposals will aim to bring technology from the conceptual stage (readiness level 0 to 1) through to feasibility verification at the prototype laboratory stage (readiness level 3 to 4). With this solicitation, NASA is particularly interested in technology developments that target the use of coherent quantum phenomena. Examples of technology developments that fall into this category are techniques based on quantum fluid behavior, techniques based on atom interferometers, and techniques based on superconductivity. Emergent nano-scale technologies based on laser cooling and trapping techniques, such as atoms on a chip and nano-laboratories, are also considered as high-payoff technologies. The potential for interdisciplinary use of the technology will be an important selection criterion.

IV. HARDWARE AND FACILITY DESCRIPTIONS

A list of hardware, facilities, and diagnostic capabilities available or planned for use in the microgravity Fundamental Physics program is listed below. Detailed descriptions of those facilities are provided on the following Web site:

http://spaceresearch.nasa.gov/research_projects/nrahardware.html

Flight Hardware

A. LOW TEMPERATURE MICROGRAVITY PHYSICS FACILITY (LTMPF) AND INSTRUMENT INSERTS

B. LCAP HARDWARE

1. Primary Atomic Reference Clock in Space (PARCS) tentatively scheduled for launch in 2007

2. Rubidium Atomic Clock Experiment (RACE), tentatively scheduled for launch in 2009

Ground-Based Facilities and Diagnostics Capabilities

Investigators may benefit from conducting reduced-gravity experiments in ground-based facilities during the experiment definition and technology development phases. NASA operates two drop towers at the Glenn Research Center (GRC) and parabolic flight research aircraft for use by investigators in this program. Please contact NASA for additional information.

NASA has adapted or developed a number of advanced techniques and technologies for microgravity fundamental physics research. Some of these techniques, such as high-resolution thermometry, SQUID readouts, and advanced thermal control systems, have already been successfully used in flight. Information about these technologies is available upon request.

V. NRA FUNDING AND SCHEDULE

The total amount of funding for this program is subject to the annual NASA budget cycle. Funds are not currently available for awards under the Fundamental Physics area of the Physical Sciences Research Division NRA. The Government's obligation to make award(s) is contingent upon the availability of appropriated funds from which payment can be made and receipt of proposals that NASA determines are acceptable for award under this NRA.

For budget planning purposes, NASA is planning to fund up to 4 flight experiment definition proposals from proposals submitted to this NRA (at a typical level of about $200,000 per year) and approximately 10 to 15 ground-based study proposals (at an average of approximately $100,000 per year) for up to 4 years. The initial fiscal year (FY) 2004 funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts associated with the timing of the initiation of research relative to the government fiscal year. **It is particularly important that the proposer realistically forecast the projected spending timeline rather than merely assume an equal amount (adjusted for inflation) of requirements for each year.** The proposed budget for ground-based studies should include researchers' salaries, travel to science and NASA/JPL meetings (for a flight investigation, roughly eight meetings per year with NASA/JPL should be anticipated, though travel activity will vary over the development of the experiment), other expenses (publication costs, computing or workstation costs), burdens, and overhead.

A complete schedule for the receipt and review of proposals to the Microgravity Fundamental Physics program is:

Notice of Intent Due:	**February 25, 2003**
Proposal Due:	**April 25, 2003**
Final Selections:	**October 2003**
Funding commences:	**No sooner than November 2003**

(dependent upon length of the procurement process)

VI. BIBLIOGRAPHY

Bibliography and World Wide Web sites that may provide useful information to proposers are listed below:

Physical Sciences Research Division general information: http://spaceresearch.nasa.gov/

The *Office of Biological and Physical Research Tasks and Bibliography*:
http://research.hq.nasa.gov/taskbook.cfm

Jet Propulsion Laboratory Fundamental Physics Information: http://funphysics.jpl.nasa.gov/

The Proceedings of the NASA/JPL 1998 and 2000 Microgravity Fundamental Physics Workshop, JPL D-18442 and JPL D-TBD

Fundamental Physics in Space Roadmap, JPL 400-808, April 1999:
http://funphysics.jpl.nasa.gov/technical/library/roadmap.html

Jet Propulsion Laboratory Low Temperature Microgravity Physics Experiments Project:
http:/ltmpf.jpl.nasa.gov/

Jet Propulsion Laboratory Laser Cooling Activities: http://horology.jpl.nasa.gov/lcap/

Questions about this program element may be directed to the Microgravity Fundamental Physics Enterprise Scientist:

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APPENDIX E
NRA 02-OBPR-03

MATERIALS SCIENCE: RESEARCH OPPORTUNITIES

I. INTRODUCTION

Research opportunities offered through this announcement encompass fundamental research under the longstanding microgravity materials science program, but in this announcement the primary objective is fundamental research needed to support strategic exploration goals. The Physical Sciences Research Division (PSRD) will attempt, as a first priority, to accommodate proposed flight experiments in existing hardware available to NASA and our international partners. Researchers are encouraged to propose against existing flight hardware.

Proposals for the conduct of fundamental research must be relevant to microgravity as defined in the following section. A section of the proposal should be included that clearly articulates the relationship between the topic of basic research and the materials technology need as described in the particular section of this NRA.

The strategic research opportunities described in subsequent sections solicit research in two specific but very broad strategic themes: In-Space Fabrication for Exploration and Materials Science for Advanced Space Propulsion. Proposals may have elements spanning strategic and fundamental research. All proposals, including those intended as fundamental, should identify any contribution of the proposed work to the achievement of NASA and Office of Biological and Physical Research (OBPR)/PSRD strategic goals. A description of NASA's strategic goals is given in the web sites listed in the Bibliography section of this Appendix.

Supporting information is available at several Web sites given in the Bibliography section of this Appendix. Persons responding to this NRA should visit those sites. Information found on the Web includes descriptions of facilities at NASA Centers that are available to successful proposers; a detailed description of the fundamental research part of the PSRD materials science program; and a description of NASA strategic goals.

It is expected that an **AMENDMENT to this NRA Appendix** will be issued approximately three months before the proposals are due. Therefore, anyone planning to submit a proposal in the materials science research topic of this NRA should register in the SYS-EYFUS system (see Appendix F) and check the http://spaceresearch.nasa.gov Web site regularly during that period of time.

II. FUNDAMENTAL RESEARCH

INTRODUCTION

NASA has supported research in microgravity materials science for over three decades. An extensive research program supports computational, theoretical, and experimental investigations in ground-based laboratories. A number of investigations are conducted using materials science research apparatus built to take advantage of the limited low-gravity test times available in ground-based facilities, such as drop towers or NASA's parabolic low gravity flight research aircraft. These ground-based experiments, along with theoretical modeling, form the basis for most of our current understanding of the effects of gravity on materials processes and phenomena. Ground-based fundamental research generally provides the intellectual underpinning of the flight program and includes new research avenues not yet considered mature enough for the flight program, theoretical and modeling studies of physicochemical systems, characterization tool development, and post-flight characterization studies.

PROGRAM RATIONALE

Materials science plays a key role in virtually all aspects of the Nation's economy.

The ability to reproducibly obtain a desired structure, and hence materials properties, is not yet at hand. Long-duration microgravity is an important tool for establishing quantitative and predictive cause-and-effect relationships among the structure, processing, and properties of materials. Establishing, understanding, and using these relationships are important elements in achieving increased international competitiveness.

The importance of materials processing lies in the understanding that the properties of most materials are dictated by the microstructure of the material, i.e. the morphology, size, spatial distribution, and chemical composition of the material's constituent phases, as well as internal defects.

Materials science deals with the relationships between the processing, structure, and properties of materials. Thus, if the relationship between processing and microstructural development is well understood, then first-principles design of a material with desired properties can indeed be realized. A fully predictive model of the relationships between processing techniques and the microstructure of a material remains an elusive goal. Microgravity offers a unique environment that can be used to extend our present understanding of materials processing in ways that are not possible in terrestrial laboratories.

Many of the techniques used to process materials are strongly influenced by the presence of a gravitational field.

For example, during the formation of a solid phase from a fluid, as is the case during crystal growth and solidification, gravitationally-driven convection of the fluid is probable. This fluid flow can alter the spatial distribution of impurities in the liquid and resulting solid, induce structural defects in the crystal, and make the results of crystal growth and solidification experiments performed on earth difficult to interpret. The presence of a gravitational field also can lead to sedimentation when two phases have different densities and at least one phase is a fluid. This sedimentation can lead to unwanted coagulation of the minority phase, as is the case during phase separation in certain polymer blends and in the colloidal processing of ceramics. A microgravity environment thus offers new opportunities to develop a deeper understanding of the relationships between many materials processing techniques and the resultant microstructures and materials properties.

RESEARCH AREAS OF INTEREST

The Materials Science Discipline Working Group's (DWG) recommendations for the key elements of the supporting scientific knowledge base underpinning materials processing technologies are listed below in order of descending priority.

- Thermodynamics and kinetics of phase transformations (e.g., mechanisms of phase selection, oriented amorphous materials, and crystallization of amorphous materials)
- Theory, modeling, and control of microstructure and defect formation (e.g., studies of morphological evolution (pattern formation), growth-induced defect formation, aerogels and foams, and colloidal and sol-gel processing)
- Interfacial phenomena (e.g., wetting behavior, self-assembly mechanisms)

Specific areas of research recommended by the DWG are listed here and described in detail in Appendix F of the previous NRA (01-OBPR-08).

- Nucleation and Metastable States
- Prediction and Control of Microstructure (Including Pattern Formation and Morphological Stability)

- Phase Separation and Interfacial Phenomena
- Transport Phenomena, including Process Modeling
- Crystal Growth, and Defect Generation and Control
- Extraterrestrial Processes and Technology Development

In addition to these traditional areas of materials science research, the success of long-duration manned space flight will demand that NASA not only understand the physiological processes and consequences of trauma and low-gravity phenomena but that it also develop viable, advanced biomaterials-based strategies for responding to the demands of long-duration manned space flight in the context of remote space travel where a rapid return to Earth is not possible. Biomaterials research is also solicited to support development of countermeasures for long-duration space flight that meet the following criteria:

- Research that would benefit from access to long-duration, high quality microgravity conditions
- Research that supports NASA's unique responsibilities for crew health and safety
- Research that supports NASA's exploration goals, for example through increases in reliability, autonomy, etc, and reductions in mass, power, volume, etc.

Specific areas of research are described in detail in a previous NRA (NRA-01-OBPR-05).

NASA is currently engaged in a comprehensive effort to establish clear, high-priority, affordable science objectives that will set the priorities for research sponsored by OBPR that strongly supports and enables NASA's vision and mission. To facilitate this prioritization, an ad-hoc external advisory committee, the Research Maximization and Prioritization (REMAP) task force, was assembled under the auspices of the NASA Advisory Council (NAC). The task force findings and recommendations provided a strong foundation for prioritizing current OBPR research based on the potential for greatest progress and impact. NASA will incorporate the NAC's response to the REMAP recommendations with advice from additional advisory boards to establish priorities to further focus the research portfolio that will be solicited in future NRAs. This focus will be aligned with NASA's strategic mission and seek to answer important fundamental scientific questions that can only be answered with the unique capabilities provided by the Agency.

It is expected that an **AMENDMENT to this NRA Appendix** will be issued approximately three months before the proposals are due. Therefore, anyone planning to submit a proposal in the materials science research topic of this NRA should register in the SYS-EYFUS system (see Appendix F) and check the http://spaceresearch.nasa.gov Web site regularly during that period of time.

III. IN-SPACE FABRICATION FOR EXPLORATION

INTRODUCTION

Future NASA missions and exploration capabilities will demand materials development and innovative in-space fabrication methods. The development of these methods is a natural extension of the microgravity materials science research program. The scientific understanding and methods developed by the program will lay the foundation for the development of In-Space Fabrication for NASA's Exploration program.

This research theme encompasses research and development to provide the materials science and processing fundamentals for fabricating components and structures in space. Materials selection issues may include the identification and development of materials best suited for the harsh environment of space. The goal is to produce materials in space for use in this environment to enable, facilitate, and support exploration. Aspects of the work involve the fabrication and repair of components and structures either contained within a spacecraft, on a celestial body, or free-floating in the space environment. This portion of the NRA supports a broad scope of efforts, including basic and applied research as well as technology development.

The examples given in this section are primarily high technical readiness level needs that NASA has identified for in-space fabrication to date. In the anticipated amendment, more detailed materials needs associated with these technological needs will be described.

Microgravity Access

The development of scientific understanding and processing equipment for in-space fabrication applications is expected to require access to reduced gravity at some point in the development process. Projects providing NASA with critical strategic research will be able to access reduced gravity using the KC-135 aircraft, or perform flight experiments on the Space Shuttle or the International Space Station. Strategic Research includes basic and applied research for which NASA relies uniquely upon OBPR in order to conduct and enable NASA's mission to explore the universe and search for life. Any research selected as a flight experiment must be conducted in a highly focused fashion with guidance from OBPR and subject to NASA and external review processes.

PROGRAM RATIONALE

In-Space Fabrication and Repairs are needed to support NASA's exploration objectives.

The realization of NASA's objectives in the exploration of the Solar System and interstellar space will require the transition from an Earth-dependent program to a self-sustaining space-based program aimed at discovering and extending life in space. The ability to maintain a continuous presence in deep space will enhance safety and reduce operational costs by the use of mature technologies capable of transforming space resources into manufactured parts and space hardware beyond Earth's surface. In-space fabrication and repair comprise a necessary group of technologies that enable the construction of spacecraft and other structures that cannot be launched due to cost, size, or structural constraints.

Materials Science research is needed to support the required technological advancements.

NASA's future exploration efforts will demand the use of mature technologies to manufacture parts and space hardware in the space environment. The construction and fortitude of large space structures in deep space (orbital or planet bound) will depend on our ability to fabricate and repair complex parts from available resources. This effort will create specific expertise and technology to handle the challenges involved in the evolution of an Earth-dependent exploration program to an autonomous, space-based program.

RESEARCH AREAS OF INTEREST

Research in this new theme supports the technology development and basic and applied research needed to develop methods for in-space fabrication. Fabrication is envisioned for a range of settings, including the "shirt-sleeve" environment of a spacecraft or outpost, as well as the "free space" environment. The research should be directed towards providing innovative, efficient, and compact solutions to the challenges faced in processing materials in the unique environment of space.

In-Space Fabrication

Fabrication of components during space missions will be one of the key elements for developing a self-sufficient space exploration capability. Specifically, this will reduce reliance on spare parts supplied from Earth and will enable production of components and deployable structures that cannot be launched from Earth, either because they are cost or size prohibitive or because they cannot withstand launch loads. These "free space" operations present a unique set of technical challenges created by the space environment. High vacuum, intense radiation of many types, large temperature gradients, high momentum objects, and levels of gravity ranging from microgravity to extraterrestrial surfaces to localized artificial gravity characterize this environment. The need for capabilities to process materials under such extreme conditions demands a thorough study of the behavior and properties of materials that will enable imaginative solutions necessary to develop robust technologies. Research, as specified by NASA's Exploration Team (NEXT), is needed in these critical areas of advanced materials and in-space fabrication processes: habitat and deployable structures, thermal protection systems, electronic and photonic materials, and dual- or multi-purpose materials. Process simulation and predictive modeling will be beneficial for designing advanced materials and fabrication processes in a cost effective manner. In addition to feedstock brought from Earth, studies should consider materials that are expected to be available in space such as salvaged spacecraft parts, or materials that can be derived from processing of lunar, planetary, or asteroid materials.

"Free space" fabrication processes will be involved in the manufacture of a variety of objects of different geometries: surfaces (e.g., solar sails and panels, solar collectors, radiators, shields), structural elements (e.g., trusses, beams, shells), ribbons and fibers (e.g., electrical and optical circuitry, antennas) and small complex parts (e.g., fasteners, mechanical devices). To achieve these goals, research is needed on the behavior of materials throughout the entire process, from handling raw materials to incorporating them into finished parts, under the unique conditions defined by the space environment. Specific areas for research are described below.

Fabrication of structural components: Both theoretical and experimental rheological studies are needed to understand the influence of the in-space environment on fabrication processes under microgravity conditions. One process being considered is free-form fabrication, which typically involves the use of a powdered form of a material and a focused heat source to build a desired part or component in a layer-by-layer fashion. However, in microgravity, the behavior of powder and molten materials is widely different from their behavior on the ground. Innovative methods (e.g. applied external fields) for controlling materials flow in "free space" fabrication are needed. Many of the processes being considered involve layering concepts. The effects of microgravity on the surface cohesion of materials during deposition, material deposition rates, effective bonding between layers, and required delay time between layers must be characterized to understand the potential characteristics, properties, and quality of free-form fabricated layered components produced in this environment. The effect of charge mitigation, adsorption, adhesion, surface temperature, and other surface effects during materials deposition are also expected to play a significant role in developing successful in-space fabrication techniques. Fabrication of complex structures will ultimately require assembly of multiple components, therefore modeling and experimental studies of subtractive (e.g., cutting and ablation), additive (e.g., melting), and adhesive methods for manufacturing structures and parts in space are required.

Fabrication of Solar Sail Systems: Advanced materials requirements for propulsion concepts are described in Section IV, Materials Science for Advanced Space Propulsion. In addition to the development of new materials for the sails, materials research is required for low packaging volume solar sail systems that are capable of being produced, self-deployed, or assembled in-space. Analysis of structural materials, adhesives, surface bonding, and the identification of multifunctional materials or advanced materials, such as multifunctional photonic materials for low mass solar sails, is needed.

Modeling of Environment and Fabrication Processes: Integral to the success of these processes is the development of models of the materials properties of components fabricated in microgravity (e.g. polymer, metallic, and ceramic parts) and the identification of the appropriate process modifications to ensure achievement of specified materials properties. Research in this area is expected to include modeling of fluid flow, heat transfer, and microstructure development, evolution, and control as influenced by materials processing methods, including microstructure control via manipulation of deposition parameters and/or heat treatment.

The NASA Exploration Team (NEXT) has developed a multi-disciplinary, long-term strategy that defines the necessary strategic investments in key technologies required to support long-term exploration goals. This team has already identified key areas (for example, in-space fabrication) where materials science research is required to enable NASA's vision. However, additional materials requirements are being identified. This strategic research area is expected to evolve as additional key technologies are identified and developed.

It is expected that an **AMENDMENT to this NRA Appendix** will be issued approximately three months before the proposals are due. Therefore, anyone planning to submit a proposal in the materials science research topic of this NRA should register in the SYS-EYFUS system (see Appendix F) and check the http://spaceresearch.nasa.gov Web site regularly during that period of time.

IV. MATERIALS SCIENCE FOR ADVANCED SPACE PROPULSION

INTRODUCTION

NASA's mission statement, presented in the Summary and Supplemental Information sections of the NRA, requires propulsion systems that can extend to the outer reaches of the solar system and beyond. While present-day technology can provide, to a certain extent, propulsion systems that can achieve those goals, they are relatively low in efficiency. Thus, trip times are much too long, and the attendant exploration packages are limited in size and complexity. In particular, significant accomplishments in materials technology are required to achieve the efficiencies that will make future propulsion systems viable. This research theme focuses on the breakthroughs in materials science that will be required in the mid-to-far-term range, or the next 10 to 25 years.

The examples given in this section are primarily high technical readiness level (TRL) needs of the NASA propulsion program. In the anticipated amendment, more detailed materials needs associated with these technological needs will be provided.

PROGRAM RATIONALE

Propulsion systems for interplanetary exploration have utilized state-of-the-art technology for decades.

The standard approach involves a high impulse over a relatively short time. The spacecraft then goes into a "coast" trajectory, which has been programmed to intercept the path of its destination, achieving the requisite contact after a flight that in some cases takes many years. Gravity assist and the resulting "launch windows" are always primary considerations in mission planning.

Future planning for space exploration assumes a steady progression in space propulsion capabilities.

The Integrated Space Transportation Plan shows advancements in launch vehicle technology that will be required to meet the strategic planning for space exploration over the next half-century, with appropriate conceptualization of space propulsion systems. More recently, the NASA Exploration Team (NEXT) has established clear exploration goals and corresponding targets for in-space propulsion systems extending to the next twenty-five years and beyond.

Nuclear systems will provide the impetus for growth in space propulsion capability.

The Nuclear Systems Initiative (NSI) has the firm support of the Administrator and the Congress; even using present-day technology, it will result in a dramatic increase in the performance of in-space propulsion systems. Assuming that the support for NSI continues, nuclear power will fill an important niche in the portfolio of space propulsion systems. However, in order to realize its full potential, there are many challenging materials issues that must be overcome.

Future space propulsion system development will likely follow the same course as aeronautics.

During the twentieth century, materials development (the aluminum airplane) transformed air travel from a high risk/low capability venture to a routine mode of transportation. Years later, jet propulsion provided the next dramatic improvement in aeronautics capability. In a very analogous manner, futuristic space propulsion concepts rest on postulated breakthroughs in the physics of propulsion systems. Nearer-term advancements rest on our ability to affect breakthrough advancements in materials science.

Materials science must lead the way for at least the next 2-3 decades of propulsion system development.

The building-block approach outlined by the NEXT is attainable over the desired time period, provided that the materials science challenges, as formidable as they appear, can be met. Furthermore, the nature of the building-block approach requires incremental advancements in system capability, so that each generation of propulsion systems can provide a "test bed" for advancement to the next level. If the Nation is to follow the course that is implied by the Mission Statement of the Agency, then meeting these materials science challenges becomes a National imperative.

RESEARCH AREAS OF INTEREST

Propellantless Propulsion

The largest contributor to the mass of a propulsion system is typically the propellant. Development of propellantless propulsion can lead to space missions that cannot be accomplished by conventional means. Two examples of propellantless propulsion are solar sails and aerocapture. A solar sail consists of a large area of thin, lightweight deployed material. Solar photons striking the sail surface impart momentum to it and therefore produce thrust. There is no propellant involved and acceleration is provided only by the impinging and reflected photons. Aerocapture is really a decelerating process that does not require propellants. As a vehicle encounters a planet's atmosphere, the drag produced by the vehicle can decelerate it enough to place it into an orbit. Materials issues exist with both of these approaches. Solar sails must be as thin and lightweight as possible but also have the required strength and the ability to be stored and deployed or fabricated in space as described in the In-Space Fabrication section. Additionally, they must maintain required properties after long-term exposure to the space environment. Aerocapture provides another set of requirements. Inflatable as well as rigid approaches have been considered. In the inflatable, deployable cases, the materials must withstand some of the same requirements as solar sails. Due to the drag involved, these materials will also experience high temperatures. The multiplicity of requirements makes these approaches challenging.

Solar Sail Materials

The far-term performance requirements for solar sail propulsion demand ultra-low density systems (<5g/m^2 system areal density). Proposals should outline a well-structured program to develop and demonstrate advances in the following areas:

- Advanced integrated structural concepts for lightweight large support structures
- Ultra-lightweight (<1g/m^2), high-strength, reflective sail materials with inherent tear resistance
- The backside of the sail, opposite the reflective surface, will require high enough emittance to maintain thermal control for desired missions
- Advanced sail materials that can operate at a distance of <0.25 AU from the sun

Aerocapture

Aerocapture technologies use the atmospheres of planets to reduce or alter the speed of a vehicle allowing for quick, nearly propellantless orbit capture. During the atmosphere pass, the energy associated with the vehicle's high speed is converted into thermal energy. Candidate aerocapture systems include rigid structures covered with thermal protection materials, "hot" structures, inflatable fore body and aft body devices, and trailing thin film ballutes. Extremely high flow velocities result in a rich variety of aerothermodynamic phenomena, which drive materials challenges. They include complex shock waves; mixed subsonic, transonic, supersonic and hypersonic flows; non-equilibrium gas chemistry; and convective and radiative heat-transfer.

Proposals should provide materials science research to address the following materials challenges:

- High temperature thin film materials for ballutes, driven by heating rates up to 1300 kW/cm^2
- High emissivity materials, to facilitate radiative cooling
- High temperature bonding agents
- Low density ablators
- Deployable (wrinkle-resistant) materials that can withstand the high heat/load environment

Electric Propulsion

Most conventional propulsion systems make use of chemically stored energy. The energy that can be transformed into vehicle momentum is limited to that stored in the fuel and oxidizer and released in the combustion process. Electric propulsion utilizes electric energy to accelerate a propellant in order to provide thrust. This type of propulsion is not limited by the energy stored chemically within the propellant. These systems can accelerate charged particles to a high energy, providing a much larger specific impulse than chemical systems; however, the flow rate is typically very small so that the thrust is low. Over a period of time, the total impulse that can be provided is much greater than available from chemical systems. Electric energy can be continually obtained via photovoltaic arrays or nuclear reactor systems. The unlimited electric energy availability and the high specific impulse of these systems give electric propulsion a large advantage for missions that require high impulse and have long mission times. Future missions utilizing primary electric propulsion will require thrusters that have a 10-50 kW_e power input and lifetimes measured in years. Long life and high power density thrusters lead to significant materials requirements for electric propulsion devices.

Ion Thruster

An ion thruster is an example of an electrostatic electric propulsion device that has been used on spacecraft for primary propulsion, attitude control, and drag makeup. Plasma is created in an ion thruster and ions are accelerated through a high voltage and discharged as a neutral ion beam to produce thrust. Future thrusters will be designed to operate for longer lifetimes and at power densities an order of magnitude greater than thrusters available today. Some life-limiting items include sputtering, both inside the discharge chamber and on the surface of the ion optics grids, and lifetimes of the neutralizer and discharge cathodes.

Hall Effect Thruster

A Hall effect thruster is another plasma thruster system that offers high specific impulse and high efficiency and is used in flight systems for Earth orbital satellites. It offers somewhat higher thrust than ion thrusters but at a lower efficiency. Life-limiting materials issues are similar to those of the ion thruster except that it does not have ion optics and utilizes a different discharge chamber design and materials.

All electric propulsion systems exhibit two significant characteristics that must be addressed: electrode erosion and the need for improved electron emitters.

Electrode erosion is a performance-limiting phenomenon in grids, electrodes, and housings associated with magneto plasma dynamic (MPD) thrusters, magneto hydrodynamic (MHD) accelerators, and ion engines. Current state-of-the-art materials are metals and alloys, all of which experience sputter erosion, which reduces efficiency and shortens functional life. Materials are needed which will enable increasing functional life to greater than ten years of continuous operation.

Electron emitters include field emitters, hollow cathodes, and filaments. The present state-of-the-art field emitter allows operation at approximately 1 ampere per square centimeter. Research effort is required that will enable electron emission greater than 10 amperes per square centimeter for continuous operations exceeding 10 years.

Nuclear Electric Propulsion (NEP)

NEP is an electric propulsion system concept consisting of various key subsystems. They include: a nuclear reactor subsystem to produce thermal energy; a power conversion subsystem to convert the thermal energy into electrical energy; and a propulsion subsystem that utilizes ion thrusters, Hall effect thrusters or possibly other electric thruster technologies. Due to the large amount of waste heat energy from the reactor and the power conversion system, the thermal control and radiators can be considered a separate subsystem. Nuclear power for in-space propulsion provides revolutionary improvement in weight, volume, and specific impulse performance over conventional chemical propulsion systems. The power densities of nuclear fuel materials are more than 7 orders of magnitude higher than chemical fuels that are used in traditional space propulsion systems. Nuclear power is also used to generate electricity at very low specific mass (kg/kW_e), which is key to enabling Lorentz force or ion thruster technology for NEP. An important requirement for NEP reactors is that they need to operate at the temperatures described above for 20,000 to 100,000 hours. The material challenges in an NEP system are substantial and may be specifically defined for each of the above listed subsystems.

Nuclear Fuels and Materials

Generally, there are three capability levels identified for reactor materials. The state-of-the-art is stainless steel clad fuels for 1000K operation. The near-term state-of-the-art is refractory clad fuels for 1340K-1600K operation. More advanced technology will include higher temperature fuels such as cermets for operation up to 2000K. There is no hydrogen present, as would be the case for thermal nuclear propulsion, but the higher temperature fuels may be helium cooled, and long life is required. Currently, power levels in the 100 to 15000 kW_e range are envisioned for nuclear electric propulsion, with 100 kW_e considered for more near-term application. Nuclear fission reactions are the most realistic source of such power levels for in-space propulsion.

NEP fuels must have adequate fuel loading, temperature, and burn up capability. Cladding materials must have properties that facilitate realistic non-nuclear system testing. Materials must be able to withstand launch loads and have good fission product retention characteristics. Near-term interest centers on demonstrating two material technologies. One is uranium nitride-based fuel/clad systems operating at peak fuel temperatures of 1800K and peak cladding temperatures of 1700K. The other is uranium dioxide fuel/clad systems operating at peak cladding temperatures of 1900K. Of additional near-term interest are fuels with the fuel loading, temperature, and burn up capability necessary to help enable low power (<50 kW_e) systems with specific mass <25 kg/kW_e. For systems approximately twenty-five years into the future, interest centers around high power systems (>1 MW_e) with a specific mass (<10 kg/kW_e). Successful proposals in this area must offer revolutionary, high payoff technology.

Significant improvement in nuclear propulsion lifetime and performance could potentially be achieved by using nuclear fuels comprised of uranium-based ceramics dispersed in a refractory matrix (cermet). In order to achieve optimum performance, the processing, characterization, and evaluation of modern cermet fuels is the key scientific challenge. Traditional cermet fuel is comprised of uranium dioxide or uranium nitride in a tungsten matrix. Due to higher chemical stability and compatibility with tungsten, uranium zirconium carbonitride (U, Zr)CN, has potential to improve the performance of cermet fuels.

Radiator Materials

Current operational space radiator systems are limited to relatively low temperature (~350K) heat rejection. These systems are largely based on low temperature alloys using Al and Mg and compatible working fluids. Extending space propulsion to higher specific impulses, especially in the case of nuclear electric propulsion, will require improved heat rejection systems. Ultra lightweight heat rejection radiator systems capable of operating for greater than ten years and in the temperature range of 400-500K could significantly improve NEP system performance. Proposals are specifically solicited for technology in this performance range. Different and potentially more advanced or higher power systems may require higher temperature heat rejection. Two potential temperature ranges of interest are 700K-1000K and 1000K-1400K. Proposals offering significant advancement in technologies associated with these temperature ranges are requested. Research proposals should include the interaction of the candidate, light-weight materials with appropriate working fluids, and coatings or surface modifications for emissivity enhancement. The emissivity enhancements must maintain excellent stability in the high vacuum and radiation environment of deep space.

Flight Weight Magnets

The challenge is to develop innovative materials, design principles, and manufacturing techniques that will allow the construction of large-volume, high-field magnet systems that are low enough in weight to be useful for flight applications. The need for high field strengths generally requires the use of either low-temperature binary-metal alloy or high-temperature ceramic oxide superconducting windings. However, the innovative use of resistive materials, such as high purity aluminum, is of limited interest for certain applications. Broadly speaking, the envisioned system applications will require magnetic fields ranging from 2 to 20 Tesla applied over large working volumes for a wide range of magnet configurations, including simple solenoids, saddle magnets, and toroidal coils.

At such high field levels, the Lorentz forces exerted on the coils are extremely large, and a very strong confinement structure is usually needed to support those forces that the conducting coils cannot withstand themselves. This need for a confinement structure generally implies a large system weight when using conventional materials and construction techniques. Therefore, the fundamental need is for innovative materials/methods for constructing coil windings and confinement structures, which optimizes the magnet's ability to withstand the enormous Lorentz forces at the lowest feasible mass.

The confinement requirements for a magnet may be fundamentally expressed in terms of the stored magnetic field energy or magnet specific energy ($W_m = VB^2/2\mu_0$ where V is the enclosed working volume, B is the magnetic flux density, and μ_0 is the magnetic permeability). The cold mass of the magnet is generally governed by the specific energy and the strength-to-weight ratio of the structural material according to the relation $m \geq W_m/(s_t/\rho)$ where s_t is the material strength and ρ is the material mass density. Common magnet systems have specific energies on the order of 5 kJ/kg, and the most advanced laboratory terrestrial magnets presently can develop specific energies around 30 kJ/kg. The specific energy requirements for many advanced propulsion systems, however, approach 1000 kJ/kg. It is believed that significant gain in magnet specific energy can be achieved by using materials and construction methods that are cost prohibitive in terrestrial applications, but increases of more than an order of magnitude may ultimately be restricted by the physical limitations of structural support materials. Innovative methods are therefore sought for achieving the highest possible magnet specific energy. Proposed solutions should be based on an integrated system perspective, which accounts for other issues such as thermal management and power.

The NASA Exploration Team (NEXT) has developed a multi-disciplinary, long-term strategy that defines the necessary strategic investments in key technologies required to support long-term exploration goals. This team has already identified key areas where materials science research is required to enable NASA's vision. However, additional materials requirements are being identified. This strategic research area is expected to evolve and mature as NEXT guidelines and directions are developed.

It is expected that an **AMENDMENT to this NRA Appendix** will be issued approximately three months before the proposals are due. Therefore, anyone planning to submit a proposal in the materials science research topic of this NRA should register in the SYS-EYFUS system (see Appendix F) and check the http://spaceresearch.nasa.gov Web site regularly during that period of time.

V. HARDWARE AND FACILITIES DESCRIPTIONS

A list of hardware, facilities, and diagnostic capabilities available or planned for use in the microgravity Materials Science program is listed below. Detailed descriptions of those facilities are provided on the following Web site:

http://spaceresearch.nasa.gov/research_projects/nrahardware.html

Flight Hardware

A. FIRST MATERIALS SCIENCE RESEARCH RACK (MSRR-1)

B. MATERIALS SCIENCE LABORATORY EXPERIMENT MODULE

1. Quench Module Insert (QMI)
2. Low Gradient Furnace (LGF) Module Insert
3. Solidification and Quench Furnace (SQF) Module Insert

C. ISS MICROGRAVITY SCIENCE GLOVEBOX

D. DISPOSITIF POUR L'ETUDE DE LA CROISSANCE ET DES LIQUIDES CRITIQUES (DECLIC)

E. MATERIALS SCIENCE LABORATORY – ELECTROMAGNETIC LEVITATOR (MSL-EML)

F. SPACEDRUMS

G. GRADIENT HEATING FURNACE

Specialized Ground-Based Research Capabilities

In addition to the specialized ground-based microgravity capabilities such as drop tubes, drop towers, and parabolic aircraft, NASA is able to support selected Principal Investigators with state-of-the-art laboratory equipment, sample preparation facilities, and computing support. These facilities are offered, on an as-available basis, through the Microgravity Science and Applications Department of the Marshall Space Flight Center, which has available trained personnel to assist all experimenters.

A. MSFC ELECTROSTATIC LEVITATOR (ESL)

B. HIGH MAGNETIC FIELD SOLIDIFICATION FACILITY

C. STEREO IMAGING VELOCIMETRY (SIV)

D. COMPUTATIONAL CAPABILITIES

E. X-RAY MICROSCOPE

F. SPREADING RESISTANCE MEASUREMENT

G. OPTICAL AND ELECTRON OPTICAL MICROSCOPY LABORATORY

H. X-RAY DIFFRACTION LABORATORY

VI. NRA FUNDING AND SCHEDULE

The total amount of funding for this program is subject to the annual NASA budget cycle. Funds are not currently available for awards under the Materials Science area of the Physical Sciences Research Division NRA. The Government's obligation to make award(s) is contingent upon the availability of appropriated funds from which payment can be made and receipt of proposals that NASA determines are acceptable for award under this NRA.

For the purposes of budget planning, we have assumed that the Physical Sciences Research Division will, in the materials science area, fund approximately 13 ground-based study proposals from those judged to be highly meritorious and program relevant (at an average of approximately $150,000 per year for up to 4 years). It is possible that additional selections may be possible if funds become available. At this time, due to severe resource limitations, we do not plan to make flight definition awards in materials science from this NRA. The initial fiscal year (FY) 2004 funding for all proposals will be adjusted to reflect partial fiscal year efforts associated with the timing of the initiation of research relative to the government fiscal year. **It is particularly important that the investigator realistically forecast the projected spending timeline rather than merely assume an equal amount (adjusted for inflation) of requirements for each year.** The proposed budget for ground-based studies should include researchers' salaries, travel to science and NASA meetings (one such meeting will be a kick-off meeting to initiate coordination of the research with the propulsion system customer), other expenses (publication costs, computing or workstation costs), burdens, and overhead.

A complete schedule for the receipt and review of proposals to the Microgravity Materials Science program is:

Notice of Intent Due:	**July 30, 2003**
Proposal Due:	**September 30, 2003**
Final Selections:	**March 2004**
Funding Commences: (dependent upon length of the procurement process)	**No sooner than May 2004**

VII. BIBLIOGRAPHY

Documents and Web sites that may provide useful information to Investigators are listed below.

Office of Biological and Physical Research Homepage at NASA Headquarters, http://spaceresearch.nasa.gov

Materials Science and Applications Department Homepage at NASA Marshall Space Flight Center, http://msad.msfc.nasa.gov/matsci/

NASA Microgravity Materials Science Conference 2000 Proceedings, NASA Conference Proceedings CP-2001-210827, March 2001.

The *Office of Biological and Physical Research Tasks and Bibliography*: http://research.hq.nasa.gov/taskbook.cfm

NASA April 12, 2002 Vision and Mission Paper, http://www.hq.nasa.gov/office/codez/plans/Vision02.pdf

Questions about this program element may be directed to the Enterprise Scientist for Materials Science:

Dr. Michael J. Wargo
Code UG
NASA Headquarters
300 E Street SW
Washington, DC 20546
Telephone: 202-358-0822
Fax: 202-358-3091
Email: mwargo@hq.nasa.gov

ACRONYM LISTING

DWG	DISCIPLINE WORKING GROUP
NASA	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NEXT	NASA EXPLORATION TEAM
NRA	NASA RESEARCH ANNOUNCEMENT
PI	PRINCIPAL INVESTIGATOR
PSRD	PHYSICAL SCIENCES RESEARCH DIVISION
OBPR	OFFICE OF BIOLOGICAL AND PHYSICAL RESEARCH
URL	UNIVERSAL RESOURCE LOCATOR

APPENDIX F
NRA 02-OBPR-03

APPLICATION PROCEDURES AND SELECTION PROCESS

Except where specifically stated otherwise in this NRA, applicants must prepare proposals in accordance with the “Instructions for Responding to NASA Research Announcements,” which is part of the NASA Federal Acquisition Regulations (FAR) Supplement (NFS), Part 1852.235-72 (APPENDIX H).

I. Instructions for Notices of Intent and Proposal Submission

A. SYS-EYFUS Registration

SYS-EYFUS is an electronic system used by NASA Headquarters to manage research solicitation activity, plan for the receipt of research proposals, track the receipt and peer evaluation of these proposals, and manage funded research (grants, cooperative agreements, etc.) sponsored by NASA’s Office of Equal Opportunity (Code E), Office of Earth Science (Code Y), Office of Human Resources & Education Division (Code F), Office of Biological and Physical Research (Code U), Office of Space Science (Code S), and the Office of Space Flight (Code M). SYS-EYFUS also supports the funding and administration of awards pursuant to selection of these research opportunities.

The SYS-EYFUS Help Desk is available at 202-479-9376. Help desk hours are from 8 a.m. to 6 p.m. Eastern time.

All investigators planning to submit a proposal to this solicitation are requested to register online with SYS-EYFUS. Comprehensive help, instructions, and contact information are provided online. SYS-EYFUS can be accessed at the following Web address:

http://proposals.hq.nasa.gov/proposal.cfm

If you have previously registered with SYS-EYFUS, you are asked to verify and update your user information. If you have forgotten your user ID or password, select the “Forgot Your Password” option and type in your first and last name to search our database. The system will send an automatic email message with your username and password to the email address listed in our database.

B. Instructions for Preparing a Notice of Intent

All investigators planning to submit a proposal in response to this solicitation are requested to submit a **non-binding** notice of intent (NOI) to propose by the due date (identified in the Summary and Supplemental Information Section of this NRA) via the Web at the following address:

http://proposals.hq.nasa.gov/proposal.cfm

1) Login to SYS-EYFUS at the URL listed above and select “New Notice of Intent.”

2) The Division Specific Opportunities screen will appear. In the selection window, highlight **Physical Sciences Research Division** and click on “Continue.”

3) The List of Existing Opportunities screen will appear. In the selection window, highlight the program element to which you are applying (see Table 1), and then click on “Continue.”

4) This will bring you to the Notice of Intent Submission Form. **All fields are required.**

a. Please select from **only** the following three options: For the proposal type field on this form, new / no prior support means that the investigator has not received NASA funding from 1999 through 2001, new / prior support means that the investigator has received NASA funding between 1999 through 2001, and revised means that the proposal is a revised version of a proposal submitted to NASA and reviewed from 1999 through 2001, but not funded. A proposal previously submitted but not funded should be identified as being "revised" even if the original Principal Investigator has changed.

5) Click on "Submit NOI Page."

6) The Team Member Page screen will appear, where you can add or remove team members. Select "Continue" if there are no other team members. To add a team member, highlight the role option on the selection list, type in first and last name, and click on "Search." When the resulting set appears, choose the appropriate radio button and click on "Add" to add the person to the NOI. After you are done, click on "Continue." **IMPORTANT:** If the team member is not listed in our database, please have them add themselves as a new user to the system. You may then add them to your team member list.

7) After continuing from the Team Members Page, your NOI will be displayed. Click on "Resubmit NOI Page" to complete your NOI submission.

8) You may edit and resubmit your NOI at any time within the NOI solicitation period for each discipline program element, provided in Table 1 in the Summary and Supplemental Information section of this NRA. Once you submit an NOI, it cannot be deleted, only edited. For title, team member, or any other changes, please edit your existing NOI and resubmit changes to avoid duplicate records.

C. Instructions for Preparing and Electronically Submitting a Proposal Cover Page

All investigators planning to submit a proposal in response to this solicitation must electronically submit proposal cover page information online and provide a hardcopy of the cover page attached to each proposal copy by the due date provided in Table 1 in the Summary and Supplemental Information section of this NRA. The proposal cover page can be submitted and printed via the Web at the following address:

http://proposals.hq.nasa.gov/proposal.cfm

1) Login to SYS-EYFUS at the URL listed above.

2) To submit a New Proposal Cover Page, click the "New Proposal Cover Page" option on the SYS-EYFUS Options screen, and the New Proposals Cover Page screen will appear.

3) If you previously submitted an NOI in response to this solicitation, choose to carry over the existing NOI. This option will populate the cover page fields with the NOI information. Edit the information as necessary, click "Continue," and proceed to number 8 below.

4) If you did not previously submit an NOI, click on "New Proposal Cover Page" option, and the Division Specific Opportunities screen will appear.

5) In the selection window, highlight **Physical Sciences Research Division** and click on "Continue."

6) The List of Existing Opportunities screen will appear. In the selection window, highlight the program element to which you are applying (see Table 1), and then click on "Continue."

7) This will bring you to the Proposal Cover Page Submission Form. Fill in all the fields. All fields are required.

   a. Please select from **only** the following three options: For the proposal type field on this form, new / no prior support means that the investigator has not received NASA funding from 1999 through 2001, new / prior support means that the investigator has received NASA funding between 1999 through 2001, and revised means that the proposal is a revised version of a proposal submitted to NASA and reviewed from 1999 through 2001, but not funded. A proposal previously submitted but not funded should be identified as being "revised" even if the original Principal Investigator has changed.

Click on "Continue."

8) The Team Member Page screen will appear, where you can add or remove team members. Select "Continue" if there are no other team members. To add a team member, highlight the role option on the selection list, type in first and last name, and click on "Search." When the resulting set appears, choose the appropriate radio button and click on "Add" to add the person to the proposal. After you are done, click on "Continue."

   You must include your authorizing official as a team member. When you complete and print the proposal cover page, you will see signature blocks both for yourself and your authorizing official. You are required to submit one original signed (by both you and your authorizing official) cover page with your proposal hard copies.

   IMPORTANT: If the team member is not listed in our database, please have them add themselves as a new user to the system. You may then add them to your team member list.

9) After continuing from the Team Member Page, the Proposal Options Page appears.

10) Please fill out the budget form by clicking on the "Budget" button, filling in project costs, and clicking "Continue." This will bring you to the Proposal Budget Review Page. Click "Continue" if the information is correct.

11) After verifying your budget information, you will be returned to the Proposal Options Page. Click the "Show/Print" button.

12) For detailed budget information, you may use your own forms or download template forms located at http://research.hq.nasa.gov/code_u/nra/current/NRA-02-OBPR-03/index.html. These forms cannot be electronically submitted. Fill out the forms and attach them to your proposal.

13) At the page entitled Proposal Information Item List, click "Continue" to preview your Proposal Cover Page. Print the cover page from your Internet browser once you have reviewed the information. The cover page must be signed by both the Principal Investigator and the authorizing official and attached to the front of your proposal before submission of hard copies to NASA.

   By signing and submitting the proposal identified on the cover sheet, the authorizing official of the proposing institution (or the individual investigator if there is no proposing institution) 1) certifies that the statements made in the proposal are true and complete to the best of his/her knowledge; 2) agrees to accept the obligations to comply with NASA Award terms and conditions if an award is made as a result of this proposal; and 3) provides certification to the following that are reproduced in their entirety in Appendix G of this NRA: (i) Certification Regarding Debarment, Suspension, and Other Responsibility Matters, (ii) Certification Regarding Lobbying, and (iii) Certification of Compliance with the NASA Regulations Pursuant to Nondiscrimination in Federally Assisted Programs.

14) You may edit and resubmit your proposal cover page at any time before the submission deadline as indicated in Table 1 in the Summary and Supplemental Information section of this NRA. Please note that once you submit a proposal cover page, it can only be edited, not deleted. For title, team member, budget, or any other changes, please edit your existing proposal cover page and resubmit changes to avoid duplicate records.

D. Instructions for Preparation and Delivery of Proposals

All proposals submitted must include the completed cover page form as described in this Appendix. The name of the Principal Investigator should appear in the upper right hand corner of each page of the proposal, except on the cover page form, where special places are provided for this information. Note that the proposal must specify the period of performance for the work described; periods of performance may be for any duration up to the maximum duration identified in the discipline-specific Appendix of this NRA to which the proposal is responding, but should be suitable for the project proposed. A brief summary of what should be included in the proposal is presented here for the benefit of the investigator. Proposals submitted in response to this Announcement must be typewritten in English and should contain at least the following elements (in order):

(1) Proposal Cover Page and Summary: Solicited Proposal Application, including certification of compliance with U.S. code (if applicable). One signed original required. The summary should succinctly convey, in broad terms, what it is the investigator wants to do, how the investigator plans to do it, why it is important, and how it meets the requirements for programmatic relevance and/or relevance to OBPR goals. Please see "Instructions for Preparing and Electronically Submitting a Proposal Cover Page" (Section I, Part C of this appendix) for instructions on how to complete the proposal cover page information.

(2) Transmittal Letter or Prefatory Material, if any (see Appendix H, "Instructions for Responding to NASA Research Announcements," for details)

(3) Proposal Title Page, with Notice of Restriction on Use and Disclosure of Proposal Information, if any (see Appendix H, "Instructions for Responding to NASA Research Announcements," for details)

(4) Table of Contents

(5) Research Project Description containing the following elements:

a. Statement of the hypothesis, objective, and value of this research.

b. Review of relevant research.

c. Justification of the need for low gravity or a space environment to meet the objectives of the experiment.

d. Description of the diagnostic measurements that would be required to satisfy the scientific objectives of any proposed low gravity experiments.

e. Estimation of time profile of reduced-gravity levels needed for the experiment or series of experiments.

f. A clear and unambiguous justification of the need to perform the experiment in space as opposed to ground-based, reduced-gravity facilities (flight definition proposals only).

g. A description of a ground-based testing program that might be needed to complete the definition of the space flight experiment requirements in terms of experiment conditions, acceleration levels and durations, control and diagnostic measurement requirements, etc.

The length of the Project Description section of the proposal should not exceed 20 pages using regular (12 point) type. Text must be printed on one side only and should have the following margins: left = 1.5"; Right, top, bottom = 1.0." Referenced figures must be included in the 20 pages of the Project Description. The Bibliography section is not considered part of the 20-page project description. Proposals that exceed the 20-page limit for the project description (22-page limit for revised proposals; see below) may not be reviewed. The proposal should contain sufficient detail to enable reviewers to make informed judgments about the overall merit of the proposed research and about the probability that the investigators will be able to accomplish their stated objectives with current resources and the resources requested. In addition, the proposal should clearly indicate the relationship between the proposed work and the research emphases defined in this Announcement. Reviewers are not required to consider information presented as appendices or to view and/or consider Web links in their evaluation of the proposal.

New applications where the investigator has received NASA funding in related fields from 1999 through 2001: Results and evidence of progress of the associated NASA supported research must be presented as part of the project description. See Appendix H, "Instructions for Responding to NASA Research Announcements," for details.

Revised applications (revisions of 1999, 2000, or 2001 submissions) must be so designated on the proposal cover page and explained in the project description. This explanation should be presented in a separate section of **no more than two (2) pages at the beginning of the project description**, and is in addition to the 20 pages allowed for the project description. Related changes to the research plan should be highlighted in the body of the project description. Changes within the proposal may be highlighted by appropriate bracketing, indenting, or changing of typography. Clearly present any work done since the prior version was submitted. **Revised applications that do not address the criticisms in the previous review will be considered non-responsive and will be returned without review.** See Appendix H, "Instructions for Responding to NASA Research Announcements," for additional information.

(6) Management Approach

Each proposal must specify a single Principal Investigator who is responsible for carrying out the proposed project and coordinating the work of other personnel involved in the project. In proposals that designate several senior professionals as key participants in the research project, the management approach section should define the roles and responsibilities of each participant and note the proportion of each individual's time to be devoted to the proposed research activity. The proposal must clearly and unambiguously state whether these key personnel have reviewed the proposal and endorsed their participation.

Co-PIs are not permitted with the sole exception when a non-U.S. Co-Investigator is proposed. This exception is described in the Co-Investigator subcategories below.

Investigators are strongly encouraged to identify only the most critically important personnel to aid in the execution of their proposals. Should such positions be necessary, Co-Investigators (Co-Is) may be identified who are critical for the successful completion of research through the contribution of unique expertise and/or capabilities, and who serve under the direction of the PI, regardless of whether they receive compensation under the award. Most NRAs require a Co-I to have a well-defined role in the research that is defined in the Management section of the proposal. Evidence of a Co-I's commitment to participate in the proposed investigation must be demonstrated by way of a brief, signed statement from him/her even if they are from the same institution as the PI.

There are three subcategories of Co-Is that a proposal may identify, as appropriate:

- A Co-I may be designated as the *Science PI* for those cases where the proposing institution does not permit that individual to formally serve as the PI as defined above. In such a case, the Science PI will be understood by NASA to be in charge of the scientific direction of the proposed work, although the formally designated PI is still held responsible for the overall direction of the effort and use of funds.

- A Co-I may be designated as an *Institutional PI* when their institution is making a major contribution to a proposal submitted by a PI from another institution.

- A Co-I from a non-U.S. institution may be designated as a *Co-Principal Investigator* (Co-PI), should such a designation serve required administrative purposes in that Co-I's institution and/or for the procurement of funding by that Co-I from their sponsoring funding authority.

Additional category positions are to be included in proposals (if that person(s) is expected to play a significant role in the execution of the proposed effort) as defined as follows:

A Postdoctoral Associate holds a Ph.D. or equivalent degree and is identified as a major participant in the execution of the proposed research. Such personnel may be identified by name or only by function in those cases where their recruitment depends on the successful selection of the proposal.

Other Professional is a description appropriate for personnel who support a proposal in a critical albeit intermittent manner, such as a consulting staff scientist or a key Project Engineer and/or Manager, who is not identified as a Co-I or Postdoctoral Associate.

A *Graduate Student* included in a proposal is working for a post-graduate degree and will support the proposed research under direction of the PI. Such a student may be identified by name or only by function in case their recruitment depends on the successful selection of the proposal.

A *Consultant* is an individual who is critical to the completion of the proposal and who is to be paid a fee for their services, which may include travel in order to consult with the PI at his/her home institution. Note that NASA's *Budget Summary* form that must be submitted as part of every proposal specifically requires the identification and justification of all Consultants.

A *Collaborator* is an unfunded position included in a proposal whose participation is less critical than a Co-I, but who is committed to provide a specific contribution to the proposal.

(7) A clear and concise description of the proposed plan for education and public outreach activities, not to exceed 5 percent of the budget. Examples include such items as involvement of students in the research activities, technology transfer plans, public information programs that will inform the general public of the benefits being gained from the research, and/or plans for incorporation of scientific results obtained into educational curricula. Proposed K-12 related education activities should adhere to and identify relevant education standards.

(8) **Prior Period of Support.** For follow-on proposals of ongoing PSRD-sponsored projects, a summary of the objectives and accomplishments of the prior period of support, including a list of published papers derived from that support, must be included as part of the investigator's justification for continued support. (Supplementary material)

(9) Summary of current and pending support for the Principal Investigator and Co-Investigators. **If the investigator is currently performing similar work under funding from another government agency, he/she must clearly explain the difference between this proposed project and the other work.** (Supplementary material)

(10) Personnel/Biographical Sketches

The biographical sketch for each investigator shall not exceed two pages. If the list of qualifications and publications exceeds two pages, select the most pertinent information (see Appendix H, "Instructions for Responding to NASA Research Announcements" for details). A sample biographical sketch form can be downloaded at http://research.hq.nasa.gov/code_u/nra/current/NRA-02-OBPR-02/index.html. These forms cannot be electronically submitted. Fill out the forms and attach them to your proposal.

(11) Facilities and Equipment (see Appendix H, "Instructions for Responding to NASA Research Announcements," for details)

(12) Detailed Budget and Supporting Budgetary Information

For detailed budget information, you may use your own forms or download template forms located at http://research.hq.nasa.gov/code_u/nra/current/NRA-02-OBPR-03/index.html. These forms cannot be electronically submitted. Please provide a detailed budget form for each year of funding requested and attach the forms to your proposal.

NASA is expected to be operating on the basis of full cost accounting as soon as possible, including all Civil Service salaries with overhead. In the interim period, proposals should use the accounting method authorized at their institutions at the time proposals are due and for the entire proposed period of performance. Funds to support the Resident Research Assistant (RRA) Postdoctoral Program costs (e.g., stipend, travel, computer time, supplies, etc.) are to be budgeted within the NASA intramural Principal Investigator budget.

If travel is planned, the proposal budget should include appropriate travel funds for visits to NASA field centers (as appropriate) and presentation of findings at professional society meetings.

In this solicitation, the terms "cost" and "budget" are used synonymously. Sufficient proposal cost detail and supporting information are required; funding amounts proposed with no explanation (e.g., Equipment: $1,000, or Labor: $6,000) may cause delays in evaluation and award. Generally, costs will be evaluated for realism, reasonableness, allowability, and allocation. The budgetary forms define the desired detail, but each category should be explained. Offerors should exercise prudent judgment in determining what to include in the proposal, as the amount of detail necessarily varies with the complexity of the proposal.

The following examples indicate the suggested method of preparing a cost breakdown:

Direct Labor

Labor costs should be segregated by titles or disciplines with estimated hours and rates for each. Estimates should include a basis of estimate, such as currently paid rates or outstanding offers to prospective employees. This format allows the Government to assess cost reasonableness by various means including comparison to similar skills at other organizations.

Other Direct Costs

Please detail, explain, and substantiate other significant cost categories as described below:

- Subcontracts: Describe the work to be contracted, estimated amount, recipient (if known), and the reason for subcontracting.
- Consultants: Identify consultants to be used, why they are necessary, the time they will spend on the project, and the rates of pay.
- Equipment: List separately. Explain the need for items costing more than $5,000. Describe basis for estimated cost. General-purpose equipment is not allowable as a

direct cost unless specifically approved by the NASA Grant Officer. Any equipment purchase requested as a direct charge must include the equipment description, how it will be used in the conduct of the basic research proposed, and why it cannot be purchased with indirect funds.

- Supplies: Provide general categories of needed supplies, the method of acquisition, and estimated cost.
- Travel: Describe the purpose of the proposed travel in relation to the grant, and provide the basis of estimate, including information on destination and number of travelers (if known).
- Other: Enter the total of direct costs not covered by a) through e). Attach an itemized list explaining the need for each item and the basis for the estimate.

Indirect Costs

Indirect costs should be explained to an extent that will allow the Government to understand the basis for the estimate. Examples of prior year historical rates, current variances from those rates, or an explanation of other basis of estimates should be included. Where costs are based on allocation percentages or dollar rates, an explanation of rate and application base relationships should be given. For example, the base to which the General and Administrative (G&A) rate is applied could be explained as: application base equals total costs before G&A less subcontracts.

All awards made as a result of this NRA maybe funded as grants, contracts, or cooperative agreements. However, while proposals submitted by "for profit" organizations are allowed, they cannot include a "fee."

(13) Appendices, if any (**reviewers are not required to consider information presented in appendices**)

One (1) signed original and twenty (20) copies of the proposal cover page and the proposals must be received at the address shown below by **4:30 p.m. Eastern time on the proposal due date for the program element, as specified in Table 1 in the Summary and Supplemental Information section of this NRA**:

Name of Program Element
Physical Sciences Research Division NRA
NASA Peer Review Services
Suite 200
500 E Street SW
Washington, DC 20024
Telephone: 202-479-9030

II. Proposal Evaluation and Awards Selection Process

The following information is specific to this NRA and **supersedes** the information contained in paragraphs (i) and (j) of Appendix H, "Instructions for Responding to NASA Research Announcements."

A. Compliance Matrix

All proposals must comply with the general requirements of the Announcement as described in both Appendices F and H, "Instructions for Responding to NASA Research Announcements." Appendix F contains specific requirements and explanations for each section of the proposal above and beyond NASA-specified requirements. Appendix H, "Instructions for Responding to NASA Research Announcements" outlines the NASA-specified requirements for proposal submission and should be used for clarification and reference. Upon receipt, proposals will be reviewed for compliance with the requirements of this Announcement. This includes

1. Submission of complete proposals specified in this Announcement. Proposals must be responsive to the areas of program element emphasis described in this Announcement and include a project description that is not more than 20 pages in length.
2. Submission of a budget that is within the guidelines specified in the particular Appendix solicitation to which the proposal is responding and is for a funding period not exceeding that described in the same Appendix.
3. Proposals that are revised versions of proposals previously submitted to NASA must be clearly designated as such on the proposal cover page and must contain an explanation of how the revised proposal has addressed criticisms from previous NASA review. This explanation should be presented in a separate section of **no more than two pages at the beginning of the project description** and is in addition to the 20 pages allowed for the project description. Related changes to the research plan should be highlighted in the body of the project description.
4. Submission of all other appropriate information as required by this NASA Research Announcement (refer to Section I, Appendix F).

Note: At NASA's discretion, non-compliant proposals may be withdrawn from the review process and returned to the investigator without further review.

Compliant proposals submitted in response to this Announcement will undergo an intrinsic scientific and technical merit review. Only those proposals most highly rated in the merit review process will undergo additional reviews for program relevance and cost.

B. Intrinsic Scientific and Technical Merit Review and Evaluation Criteria

The three principal factors of the Research and Development (R&D) investment criteria recently issued by the Office of Science and Technology Policy and the Office of Management and Budget are *Relevance, Quality,* and *Performance.* R&D investments must have clear plans and must be *relevant* to national priorities, agency missions, relevant fields, and "customer" needs. While there are other examples within the OBPR portfolio, the emphasis on strategic research and alignment with the NASA Exploration Team initiatives represent relevance to agency missions and "customer" needs. Programs should maximize the *quality* of R&D through the use of clearly stated, defensible methods of awarding a significant majority of their funding. The use of competitive, peer-review process for award of research grants has been and will continue to be the foundation for assuring the quality of PSRD research. Finally, R&D programs are expected to maintain a set of high priority, multi-year R&D objectives with annual *performance* outputs and milestones that show how one of more outcomes will be reached. Elements of performance measurement for PSRD research grants may include

- Technical society awards recognizing outstanding work;
- Publications in the top scientific journals within the discipline as well as to the broader scientific community; and

- Inventions and patents.

Taking risks and working towards challenging goals are important aspects of good research management, especially for basic research where innovation and breakthroughs are among the results. The intent of the investment criteria is not to drive basic research programs to pursue less risky research that has a greater chance of success.

The above investment criteria are clearly reflected in the evaluation process that will be used for this NRA. The evaluation process for this NRA will be based on a peer review of the proposal's intrinsic scientific and technical merit, articulated relevance to the Physical Sciences program, and cost of the research plan. The reviewers will be scientific and technical experts from government, academia, and industry. Each proposal will be reviewed independently by members of the review panel and discussed at a review panel meeting to determine a consensus evaluation for the proposal. For flight definition proposals, NASA will also conduct engineering and management reviews to establish feasibility of the planned implementation, to review risk mitigation plans, to evaluate the experience of the implementing organization, and to review the budget. The external peer review and internal engineering review panels will be coordinated by the NASA Enterprise Discipline Scientists. Consideration of the programmatic objectives of this NRA will be applied by NASA to ensure enhancement of program breadth, balance, and diversity. NASA will also consider the cost of the proposal. The PSRD Director will make the final selection based on science panel evaluations and programmatic recommendations.

Evaluation of the intrinsic merit of the proposal includes consideration of the following factors, in descending order of importance:

- Overall scientific and technical merit, including evidence of unique or innovative methods, approaches, or concepts, the potential for new discoveries or understanding, or delivery of new technologies or products and associated schedules.
- Qualifications, capabilities, and experience of the proposed Principal Investigator, team leader, or key personnel who are critical in achieving the proposal objectives.
- Institutional resources and experience that are critical in achieving the proposal objectives.
- Overall standing among similar proposals available for evaluation and/or evaluation against the known state-of-the-art.

Recommendations for funding for the proposals submitted to this NRA will be based on the peer evaluation of each proposal, programmatic balance, and cost. The scientific peer review panel will assign each proposal a numerical merit score based on the above factors. The score assigned by the peer review panel will not be affected by the cost of the proposed work nor will it reflect the programmatic relevance of the proposed work to NASA. However, the panel will be asked to include in their critique of each proposal any comments they may have concerning the proposal's budget and relevance to NASA. For flight proposals, the engineering and management panel will evaluate the feasibility and complexity of accomplishing each investigation along with an estimate of total cost for flight hardware development. NASA will take these assessments into consideration in making the final selection of experiments that will be considered for flight definition.

C. Evaluation of Programmatic Relevance and Cost

Evaluation of the cost of a proposed effort includes consideration of the realism and reasonableness of the proposed cost and the relationship of the proposed cost to available funds. NASA reserves the right to act in the best interest of the federal government in the matter of proposal evaluation and funding. NASA reserves the right to determine the funding mechanism for any proposal selected for funding.

Evaluation of a proposal’s relevance to NASA’s objectives includes the consideration of the potential contribution of the effort to NASA’s mission. This is especially important for strategic research proposals. Proposals should demonstrate knowledge of NASA’s mission plans and/or technology gaps, and state clearly the benefits that will result upon successful completion of the funded work. References for this information are primarily found in the discipline-specific solicitations and the references provided in the Bibliography sections of Appendices A–E, and also in the References section of this Appendix.

D. Development of Selection Recommendation

The principal elements considered in the evaluation of proposals solicited by this NRA are relevance to NASA's objectives, intrinsic merit, and cost. Of these, intrinsic merit has the greatest weight, followed by relevance to NASA's objectives, which has slightly lesser weight. Both of these elements have greater weight than cost.

The information resulting from these reviews, as described above, will be used to prepare a **selection recommendation** developed by NASA Enterprise Scientists and managers for each of the program elements described in this Announcement. This recommendation will be based on:

1. The scientific or technical merit review score from the peer review panel.
2. The programmatic relevance.
3. The cost of each proposal.

This **selection recommendation** is the responsibility of the NASA Enterprise Scientist. Selection for funding will be made by the Selection Official identified in the Summary and Supplemental Information Section of this NRA.

At the end of the selection process, each proposing organization is notified of its selection or nonselection status. NASA provides debriefings to those investigators who request one. In all cases, the Government's obligation to make awards is contingent upon the availability of appropriated funds from which payment can be made, and upon the receipt of proposals in response to this NRA that NASA determines are acceptable for award. The selection letters will include a statement indicating the selected organization's business office will be contacted by a NASA Contracting or Grant Officer, who is the only official authorized to obligate the Government, and a reminder that any costs incurred by the investigator in anticipation of an award are at their own risk. Selection notification will be made by a letter signed by the selection official.

The NASA Procurement Office will determine the type of award instrument, request further business data, negotiate the resultant action, and are the only personnel with the authority to obligate government funds.

NASA reserves the right to offer selection of only a portion of a proposal. In these instances, the investigator will be given the opportunity to accept or decline the offer.

III. Eligibility

Participation in this program is open to all categories of U.S. and non-U.S. organizations, including educational institutions, industry, nonprofit institutions, NASA Centers, and other Government agencies. Historically Black Colleges and Universities (HBCUs), other minority educational institutions, and small businesses and organizations owned and controlled by socially and economically disadvantaged individuals or women are particularly encouraged to apply. Only approved proposals from U.S. institutions will be selected for funding. Principal Investigators may collaborate with universities, Federal Government laboratories, the private sector, and state and local government laboratories. In all such arrangements, the applying entity is expected to be responsible for administering the project according to the management approach presented in the proposal.

The applying entity must have in place a documented base of ongoing high quality research in science and technology or in those areas of science and engineering clearly relevant to the specific programmatic objectives and research emphases indicated in this Announcement. Present or prior support by NASA of research or training in any institution or for any investigator is neither a prerequisite to submission of a proposal nor a competing factor in the selection process.

IV. Guidelines for International Participation

Guidelines for International Participation are detailed in paragraph I of Appendix H of this Announcement**.**

Export Control Guidelines Applicable to Foreign Proposals and Proposals Including Foreign Participation. Foreign proposals and proposals including foreign participation must include a section discussing compliance with U.S. export laws and regulations, e.g.., 22 CFR Parts 120-130 and 15 CFR Parts 730-774, as applicable to the circumstances surrounding the particular foreign participation. The discussion must describe in detail the proposed foreign participation and is to include, but not be limited to, whether or not the foreign participation may require the prospective investigator to obtain the prior approval of the Department of State or the Department of Commerce via a technical assistance agreement or an export license, or whether a license exemption/exception may apply. If prior approvals via licenses are necessary, discuss whether the license has been applied for or if not, the projected timing of the application and any implications for the schedule. Information regarding U.S. export regulations is available at http://www.pmdtc.org/ and http://www.bxa.doc.gov/. Investigators are advised that under U.S. law and regulations, spacecraft and their specifically designed, modified, or configured systems, components, and parts are generally considered “Defense Articles” on the United States Munitions List and are subject to the provisions of the International Traffic in Arms Regulations (ITAR), 22 CFR Parts 120-130.

V. Program Reporting

It is expected that results from funded research will be submitted to peer-reviewed journals as the work progresses. Only published papers that acknowledge NASA’s support and identify the grant or contract will be counted as resulting from the research project and used to evaluate its productivity.

Annual Reporting. The Office of Biological and Physical Research publishes a comprehensive annual document titled OBPR Program Tasks and Bibliography (Task Book) which includes descriptions of all peer-reviewed activities funded by the Division during the previous fiscal year. Since its inception, the Task Book has served as an invaluable source of information for OBPR as well as the scientific and technical communities.

Investigators are required to provide NASA with this annual summary information. This information will be made available to the scientific community and will be used to assess the strength of the Division’s programs. It will also serve as the basis for determining the degree of progress of the project. The information provided for the Task Book will meet the requirements for annual reporting requirements and the task book. This report will be due 60 days prior to the anniversary date of the grant, contract, or cooperative agreement start date.

The information requested will include

- an abstract
- a brief statement of progress during the fiscal year
- a brief statement of benefits of the research with respect to life on Earth
- a bibliographic list for the fiscal year
- a copy or reprint of each publication listed in the bibliography for the fiscal year
- a listing of presentations or activities conducted at 6-12 educational institutions
- a listing of interactions, presentations, or other activities with the general public
- copies of publications
- a statement of progress

- potential scientific, technological, economic or societal impact

Note that although this publication will be made available to the general scientific community, it is not a substitute for traditional scientific reporting in journals and elsewhere.

All articles submitted for publication must include the following statement: “This research was funded in whole or in part by a grant (contract or cooperative agreement) from the Office of Biological and Physical Research of the National Aeronautics and Space Administration.” Publications not including this acknowledgement will not be considered to be the product of NASA-funded research when NASA assesses the progress of the grant.

Final Report. A final report is required that shall include all peer-reviewed publications.

VI. Support of Education and Public Outreach

OBPR envisions that the selected proposals will be structured and operated in a manner that supports the nation’s educational initiatives and goals (including support of historically black colleges and universities and other minority universities), and in particular the need to promote scientific and technical education at all levels. OBPR envisions that the selected proposals will support the goals for public awareness and outreach to the general public (see Summary and Supplemental Information section). The selected principal investigators are invited to participate in OBPR-funded educational programs.

OBPR Policy for Education (Grades 6-12) and Public Outreach

The proposal represents an opportunity for NASA to enhance and broaden the public’s understanding and appreciation of the value of OBPR research in the context of NASA’s mission. Therefore, all investigators are strongly encouraged to promote general scientific literacy and public understanding of OBPR research through formal and/or informal education opportunities. If appropriate, proposals should include a clear and concise description of the education and outreach activities proposed. Examples include such items as involvement of students in the research activities, technology transfer plans, public information programs that will inform the general public of the benefits being gained from the research, and/or plans for incorporation of scientific results obtained into educational curricula consistent with educational standards. Where appropriate, the supported institution will be required to produce, in collaboration with NASA, a plan for communicating to the public the value and importance of their work.

Once NRA selections are made, the selected PIs will have an opportunity to request additional funding through an OBPR-sponsored pilot program to implement an education outreach program at the grades 6-12 level, at an amount not to exceed $10,000 per year for the term of the grant, contract, or cooperative agreement. A request for proposal will accompany the selection notification letter. Proposals will be due within 60 days of selection notification and shall be limited to 4 pages. A review of these proposals by educational specialists will determine which proposals will be funded.

VII. References

A. General References

Guidebook for Proposers Responding to a NASA Research Announcement (NRA), 2003 edition: http://www.hq.nasa.gov/office/procurement/nraguidebook/gdbkcvr.html.

OBPR Program Tasks and Bibliography (Task Books) are available online at the following address: http://research.hq.nasa.gov/taskbook.cfm

NASA 2000 Strategic Plan: http://www.hq.nasa.gov/office/codez/plans/pl2000.pdf

Office of Biological and Physical Research Homepage at NASA Headquarters: http://spaceresearch.nasa.gov

Viskanta, Raymond, et al., "Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies," (ISBN 0-309-06491-0), The National Academy of Sciences, Space Studies Board, 2000.

Proceedings of the Materials Science for Advanced Space Propulsion Workshop, Huntsville, AL, October 8–10, 2001. Available on the Web at http://msad.msfc.nasa.gov/mwd

NASA April 12, 2002 Vision and Mission Paper: http://www.hq.nasa.gov/office/codez/plans/Vision02.pdf

Spacecraft Fire Safety Workshop, June 2001: http://www.ncmr.org/events/firesafety.

Fred J. Kohl, Bhim S. Singh, J. Iwan Alexander, Nancy J. Shaw, Myron E. Hill and Frank G. Gati, "The NASA Microgravity Fluid Physics Program Knowledge for use on Earth and Future Space Missions," 53rd International Astronautical Congress, The World Space Congress, Oct. 10–19, 2002, Houston, Texas.

APPENDIX G
NRA 02-OBPR-03

CERTIFICATION REGARDING DEBARMENT, SUSPENSION, AND OTHER RESPONSIBILITY MATTERS

PRIMARY COVERED TRANSACTIONS

This certification is required by the regulations implementing Executive Order 12549, Debarment and Suspension, 14 CFR Part 1269.

A. The applicant certifies that it and its principals:

(a) Are not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency;

(b) Have not within a three-year period preceding this application been convicted or had a civil judgment rendered against them for commission of fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (Federal, State, or Local) transaction or contract under a public transaction; violation of Federal or State antitrust statutes or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property;

(c) Are not presently indicted for or otherwise criminally or civilly charged by a government entity (Federal, State, or Local) with commission of any of the offenses enumerated in paragraph A.(b) of this certification; and

(d) Have not within a three-year period preceding this application/proposal had one or more public transactions (Federal, State, or Local) terminated for cause or default; and

B. Where the applicant is unable to certify to any of the statements in this certification, he or she shall attach an explanation to this application.

C. Certification Regarding Debarment, Suspension, Ineligibility and Voluntary Exclusion - Lowered Tier Covered Transactions (Subgrants or Subcontracts)

a) The prospective lower tier participant certifies, by submission of this proposal, that neither it nor its principles is presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from participation in this transaction by any federal department of agency.

b) Where the prospective lower tier participant is unable to certify to any of the statements in this certification, such prospective participant shall attach an explanation to this proposal.

CERTIFICATION REGARDING LOBBYING

As required by S 1352 Title 31 of the U.S. Code for persons entering into a grant or cooperative agreement over $100,000, the applicant certifies that:

(a) No Federal appropriated funds have been paid or will be paid by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, in connection with making of any Federal grant, the entering into of any cooperative, and the extension, continuation, renewal, amendment, or modification of any Federal grant or cooperative agreement;

(b) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting an officer or employee of any agency, Member of Congress, an or an employee of a Member of Congress in connection with this Federal grant or cooperative agreement, the undersigned shall complete Standard Form - LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.

(c) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subgrants, contracts under grants and cooperative agreements, and subcontracts), and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by S1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

CERTIFICATION OF COMPLIANCE WITH THE NASA REGULATIONS PURSUANT TO NONDISCRIMINATION IN FEDERALLY ASSISTED PROGRAMS

The (Institution, corporation, firm, or other organization on whose behalf this assurance is signed, hereinafter called “Applicant”) hereby agrees that it will comply with Title VI of the Civil Rights Act of 1964 (P.L. 88-352), Title IX of the Education Amendments of 1962 (20 U.S. 1680 et seq.), Section 504 of the Rehabilitation Act of 1973, as amended (29 U.S. 794), and the Age Discrimination Act of 1975 (42 U.S. 16101 et seq..), and all requirements imposed by or pursuant to the Regulation of the National Aeronautics and Space Administration (14 CFR Part 1250) (hereinafter called “NASA”) issued pursuant to these laws, to the end that in accordance with these laws and regulations, no person in the United States shall, on the basis of race, color, national origin, sex, handicapped condition, or age be excluded from participating in, be denied the benefits of, or be otherwise subjected to discrimination under any program or activity for which the Applicant receives federal financial assistance from NASA; and hereby give assurance that it will immediately take any measure necessary to effectuate this agreement.

If any real property or structure thereon is provided or improved with the aid of federal financial assistance extended to the Applicant by NASA, this assurance shall obligate the Applicant, or in the case of any transfer of such property, any transferee, for the period during which the real property or structure is used for a purpose for which the federal financial assistance is extended or for another purpose involving the provision of similar services or benefits. If any personal property is so provided, this assurance shall obligate the Applicant for the period during which the federal financial assistance is extended to it by NASA.

This assurance is given in consideration of and for the purpose of obtaining any and all federal grants, loans, contracts, property, discounts, or other federal financial assistance extended after the date hereof to the Applicant by NASA, including installment payments after such date on account of applications for federal financial assistance which were approved before such date. The Applicant recognized and agrees that such federal financial assistance will be extended in reliance on the representations and agreements made in this assurance, and the United States shall have the right to seek judicial enforcement of this assurance. His assurance is binding on the Applicant, its successors, transferees, and assignees, and the person or persons whose signatures appear below are authorized to sign on behalf of the Applicant.

INSTRUCTIONS FOR RESPONDING TO NASA RESEARCH ANNOUNCEMENTS (MAY 2002)

(a) **General.**

(1) Proposals received in response to a NASA Research Announcement (NRA) will be used only for evaluation purposes. NASA does not allow a proposal, the contents of which are not available without restriction from another source, or any unique ideas submitted in response to an NRA to be used as the basis of a solicitation or in negotiation with other organizations, nor is a pre-award synopsis published for individual proposals.

(2) A solicited proposal that results in a NASA award becomes part of the record of that transaction and may be available to the public on specific request; however, information or material that NASA and the awardee mutually agree to be of a privileged nature will be held in confidence to the extent permitted by law, including the Freedom of Information Act.

(3) NRAs contain programmatic information and certain requirements which apply only to proposals prepared in response to that particular announcement. These instructions contain the general proposal preparation information which applies to responses to all NRAs.

(4) A contract, grant, cooperative agreement, or other agreement may be used to accomplish an effort funded in response to an NRA. NASA will determine the appropriate award instrument. Contracts resulting from NRAs are subject to the Federal Acquisition Regulation and the NASA FAR Supplement. Any resultant grants or cooperative agreements will be awarded and administered in accordance with the NASA Grant and Cooperative Agreement Handbook (NPG 5800.1).

(5) NASA does not have mandatory forms or formats for responses to NRAs; however, it is requested that proposals conform to the guidelines in these instructions. NASA may accept proposals without discussion; hence, proposals should initially be as complete as possible and be submitted on the proposers' most favorable terms.

(6) To be considered for award, a submission must, at a minimum, present a specific project within the areas delineated by the NRA; contain sufficient technical and cost information to permit a meaningful evaluation; be signed by an official authorized to legally bind the submitting organization; not merely offer to perform standard services or to just provide computer facilities or services; and not significantly duplicate a more specific current or pending NASA solicitation.

(b) **NRA-Specific Items.** Several proposal submission items appear in the NRA itself: the unique NRA identifier; when to submit proposals; where to send proposals; number of copies required; and sources for more information. Items included in these instructions may be supplemented by the NRA.

(c) The following information is needed to permit consideration in an objective manner. NRAs will generally specify topics for which additional information or greater detail is desirable. Each proposal copy shall contain all submitted material, including a copy of the transmittal letter if it contains substantive information.

(1) **Transmittal Letter or Prefatory Material.**

(i) The legal name and address of the organization and specific division or campus identification if part of a larger organization;

(ii) A brief, scientifically valid project title intelligible to a scientifically literate reader and suitable for use in the public press;

(iii) Type of organization: e.g., profit, nonprofit, educational, small business, minority, women-owned, etc.;

(iv) Name and telephone number of the principal investigator and business personnel who may be contacted during evaluation or negotiation;

(v) Identification of other organizations that are currently evaluating a proposal for the same efforts;

(vi) Identification of the NRA, by number and title, to which the proposal is responding;

(vii) Dollar amount requested, desired starting date, and duration of project;
(viii) Date of submission; and

(ix) Signature of a responsible official or authorized representative of the organization, or any other person authorized to legally bind the organization (unless the signature appears on the proposal itself).

(2) **Restriction on Use and Disclosure of Proposal Information.** Information contained in proposals is used for evaluation purposes only. Offerors or quoters should, in order to maximize protection of trade secrets or other information that is confidential or privileged, place the following notice on the title page of the proposal and specify the information subject to the notice by inserting an appropriate identification in the notice. In any event, information contained in proposals will be protected to the extent permitted by law, but NASA assumes no liability for use and disclosure of information not made subject to the notice.

Notice

Restriction on Use and Disclosure of Proposal Information

The information (data) contained in [insert page numbers or other identification] of this proposal constitutes a trade secret and/or information that is commercial or financial and confidential or privileged. It is furnished to the Government in confidence with the understanding that it will not, without permission of the offeror, be used or disclosed other than for evaluation purposes; provided, however, that in the event a contract (or other agreement) is awarded on the basis of this proposal the Government shall have the right to use and disclose this information (data) to the extent provided in the contract (or other agreement). This restriction does not limit the Government's right to use or disclose this information (data) if obtained from another source without restriction.

(3) **Abstract.** Include a concise (200-300 word if not otherwise specified in the NRA) abstract describing the objective and the method of approach.

(4) **Project Description.**

(i) The main body of the proposal shall be a detailed statement of the work to be undertaken and should include objectives and expected significance; relation to the present state of knowledge; and relation to previous work done on the project and to related work in progress elsewhere. The statement should outline the plan of work, including the broad design of experiments to be undertaken and a description of experimental methods and procedures. The project description should address the evaluation factors in these instructions and any specific factors in the NRA. Any substantial collaboration with individuals not referred to in the budget or use of consultants should be described. Subcontracting significant portions of a research project is discouraged.

(ii) When it is expected that the effort will require more than one year, the proposal should cover the complete project to the extent that it can be reasonably anticipated. Principal emphasis should be on the first year of work, and the description should distinguish clearly between the first year's work and work planned for subsequent years.

(5) **Management Approach.** For large or complex efforts involving interactions among numerous individuals or other organizations, plans for distribution of responsibilities and arrangements for ensuring a coordinated effort should be described.

(6) **Personnel.** The principal investigator is responsible for supervision of the work and participates in the conduct of the research regardless of whether or not compensated under the award. A short biographical sketch of the principal investigator, a list of principal publications and any exceptional qualifications should be included. Omit social security number and other personal items which do not merit consideration in evaluation of the proposal. Give similar biographical information on other senior professional personnel who will be directly associated with the project. Give the names and titles of any other scientists and technical personnel associated substantially with the project in an advisory capacity. Universities should list the approximate number of students or other assistants, together with information as to their level of academic attainment. Any special industry-university cooperative arrangements should be described.

(7) **Facilities and Equipment.**

(i) Describe available facilities and major items of equipment especially adapted or suited to the proposed project, and any additional major equipment that will be required. Identify any Government-owned facilities, industrial plant equipment, or special tooling that are proposed for use. Include evidence of its availability and the cognizant Government points of contact.

(ii) Before requesting a major item of capital equipment, the proposer should determine if sharing or loan of equipment already within the organization is a feasible alternative. Where such arrangements cannot be made, the proposal should so state. The need for items that typically can be used for research and non-research purposes should be explained.

(8) **Proposed Costs (U.S. Proposals Only).**

(i) Proposals should contain cost and technical parts in one volume: do not use separate "confidential" salary pages. As applicable, include separate cost estimates for salaries and wages; fringe benefits; equipment; expendable materials and supplies; services; domestic and foreign travel; ADP expenses; publication or page charges; consultants; subcontracts; other miscellaneous identifiable direct costs; and indirect costs. List salaries and wages in appropriate organizational categories (e.g., principal investigator, other scientific and engineering professionals, graduate students, research assistants, and technicians and other non-professional personnel). Estimate all staffing data in terms of staff-months or fractions of full-time.

(ii) Explanatory notes should accompany the cost proposal to provide identification and estimated cost of major capital equipment items to be acquired; purpose and estimated number and lengths of trips planned; basis for indirect cost computation (including date of most recent negotiation and cognizant agency); and clarification of other items in the cost proposal that are not self-evident. List estimated expenses as yearly requirements by major work phases.

(iii) Allowable costs are governed by FAR Part 31 and the NASA FAR Supplement Part 1831 (and OMB Circulars A-21 for educational institutions and A-122 for nonprofit organizations).

(iv) Use of NASA funds--NASA funding may not be used for foreign research efforts at any level, whether as a collaborator or a subcontract. The direct purchase of supplies and/or services, which do not constitute research, from non-U.S. sources by U.S. award recipients is permitted. Additionally, in accordance with the National Space Transportation Policy, use of a non-U.S. manufactured launch vehicle is permitted only on a no-exchange-of-funds basis.

(9) **Security.** Proposals should not contain security classified material. If the research requires access to or may generate security classified information, the submitter will be required to comply with Government security regulations.

(10) **Current Support.** For other current projects being conducted by the principal investigator, provide title of project, sponsoring agency, and ending date.

(11) **Special Matters.**

(i) Include any required statements of environmental impact of the research, human subject or animal care provisions, conflict of interest, or on such other topics as may be required by the nature of the effort and current statutes, executive orders, or other current Government-wide guidelines.

(ii) Proposers should include a brief description of the organization, its facilities, and previous work experience in the field of the proposal. Identify the cognizant Government audit agency, inspection agency, and administrative contracting officer, when applicable.

(d) **Renewal Proposals.**

(1) Renewal proposals for existing awards will be considered in the same manner as proposals for new endeavors. A renewal proposal should not repeat all of the information that was in the original proposal. The renewal proposal should refer to its predecessor, update the parts that are no longer current, and indicate what elements of the research are expected to be covered during the period for which support is desired. A description of any significant findings since the most recent progress report should be included. The renewal proposal should treat, in reasonable detail, the plans for the next period, contain a cost estimate, and otherwise adhere to these instructions.

(2) NASA may renew an effort either through amendment of an existing contract or by a new award.

(e) **Length.** Unless otherwise specified in the NRA, effort should be made to keep proposals as brief as possible, concentrating on substantive material. Few proposals need exceed 15-20 pages. Necessary detailed information, such as reprints, should be included as attachments. A complete set of attachments is necessary for each copy of the proposal. As proposals are not returned, avoid use of "one-of-a-kind" attachments.

(f) **Joint Proposals.**

(1) Where multiple organizations are involved, the proposal may be submitted by only one of them. It should clearly describe the role to be played by the other organizations and indicate the legal and managerial arrangements contemplated. In other instances, simultaneous submission of related proposals from each organization might be appropriate, in which case parallel awards would be made.

(2) Where a project of a cooperative nature with NASA is contemplated, describe the contributions expected from any participating NASA investigator and agency facilities or equipment which may be required. The proposal must be confined only to that which the proposing organization can commit itself. "Joint" proposals which specify the internal arrangements NASA will actually make are not acceptable as a means of establishing an agency commitment.

(g) **Late Proposals.** Proposals or proposal modifications received after the latest date specified for receipt may be considered if a significant reduction in cost to the Government is probable or if there are significant technical advantages, as compared with proposals previously received.

(h) **Withdrawal.** Proposals may be withdrawn by the proposer at any time before award. Offerors are requested to notify NASA if the proposal is funded by another organization or of other changed circumstances which dictate termination of evaluation.

(i) **Evaluation Factors.**

(1) Unless otherwise specified in the NRA, the principal elements (of approximately equal weight) considered in evaluating a proposal are its relevance to NASA's objectives, intrinsic merit, and cost.

(2) Evaluation of a proposal's relevance to NASA's objectives includes the consideration of the potential contribution of the effort to NASA's mission.

(3) Evaluation of its intrinsic merit includes the consideration of the following factors of equal importance:

(i) Overall scientific or technical merit of the proposal or unique and innovative methods, approaches, or concepts demonstrated by the proposal.

(ii) Offeror's capabilities, related experience, facilities, techniques, or unique combinations of these which are integral factors for achieving the proposal objectives.

(iii) The qualifications, capabilities, and experience of the proposed principal investigator, team leader, or key personnel critical in achieving the proposal objectives.

(iv) Overall standing among similar proposals and/or evaluation against the state-of-the-art.

(4) Evaluation of the cost of a proposed effort may include the realism and reasonableness of the proposed cost and available funds.

(j) **Evaluation Techniques.** Selection decisions will be made following peer and/or scientific review of the proposals.. Several evaluation techniques are regularly used within NASA. In all cases proposals are subject to scientific review by discipline specialists in the area of the proposal. Some proposals are reviewed entirely in-house, others are evaluated by a combination of in-house and selected external reviewers, while yet others are subject to the full external peer review technique (with due regard for conflict-of-interest and protection of proposal information), such as by mail or through assembled panels. The final decisions are made by a NASA selecting official. A proposal which is scientifically and programmatically meritorious, but not selected for award during its initial review, may be included in subsequent reviews unless the proposer requests otherwise.

(k) **Selection for Award.**

(1) When a proposal is not selected for award, the proposer will be notified. NASA will explain generally why the proposal was not selected. Proposers desiring additional information may contact the selecting official who will arrange a debriefing.

(2) When a proposal is selected for award, negotiation and award will be handled by the procurement office in the funding installation. The proposal is used as the basis for negotiation. The contracting officer may request certain business data and may forward a model award instrument and other information pertinent to negotiation.

(l) **Additional Guidelines Applicable to Foreign Proposals and Proposals Including Foreign Participation.**

(1) NASA welcomes proposals from outside the U.S. However, foreign entities are generally not eligible for funding from NASA. Therefore, unless otherwise noted in the NRA, proposals from foreign entities should not include a cost plan unless the proposal involves collaboration with a U.S. institution, in which case a cost plan for only the participation of the U.S. entity must be included. Proposals from foreign entities and proposals from U.S. entities that include foreign participation must be endorsed by the respective government agency or funding/sponsoring institution in the country from which the foreign entity is proposing. Such endorsement should indicate that the proposal merits careful consideration by NASA, and if the proposal is selected, sufficient funds will be made available to undertake the activity as proposed.

(2) All foreign proposals must be typewritten in English and comply with all other submission requirements stated in the NRA. All foreign proposals will undergo the same evaluation and selection process as those originating in the U.S. All proposals must be received before the established closing date. Those received after the closing date will be treated in accordance with paragraph (g) of this provision. Sponsoring foreign government agencies or funding institutions may, in exceptional situations,

forward a proposal without endorsement if endorsement is not possible before the announced closing date. In such cases, the NASA sponsoring office should be advised when a decision on endorsement can be expected.

(3) Successful and unsuccessful foreign entities will be contacted directly by the NASA sponsoring office. Copies of these letters will be sent to the foreign sponsor. Should a foreign proposal or a U.S. proposal with foreign participation be selected, NASA's Office of External Relations will arrange with the foreign sponsor for the proposed participation on a no-exchange-of-funds basis, in which NASA and the non-U.S. sponsoring agency or funding institution will each bear the cost of discharging their respective responsibilities.

(4) Depending on the nature and extent of the proposed cooperation, these arrangements may entail:

(i) An exchange of letters between NASA and the foreign sponsor; or

(ii) A formal Agency-to-Agency Memorandum of Understanding (MOU).

(m) **Cancellation of NRA.** NASA reserves the right to make no awards under this NRA and to cancel this NRA. NASA assumes no liability for canceling the NRA or for anyone's failure to receive actual notice of cancellation.